GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION
SPONSORED PROJECT INITIATION

Date: September 30, 1977

Project Title: Energy Conservation Study of the Plating and Surface Finishing Industry - Phase I

Project No: A-2042

Project Director: ~~J. F. Lowry~~

Sponsor: Energy Research & Development Admin.; Oak Ridge Operations; Oak Ridge, TN

Agreement Period: From 8/1/77 Until ~~7/31/78~~ 2/28/79

Type Agreement: Contract No. EC-77-S-05-5487

Amount: $82,578

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Sponsor Contact Person (s):

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Defense Priority Rating:

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CA-3 (3/76)

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION

Date: 2/1/79

Project Title: Energy Conservation Study of the Plating and Surface Finishing Industry - Phase I

OHR -

Project No: A-2042

Project Director: D. A. Mazzeo

Sponsor: Department of Energy

No Cert. req. -
Cont. says Tech owns All

Effective Termination Date: 1/24/79

Clearance of Accounting Charges: 2/28/79

Grant/Contract Closeout Actions Remaining:

- X Final Invoice and Closing Documents
- X Final Fiscal Report
- _ Final Report of Inventions
- _ Govt. Property Inventory & Related Certificate
- _ Classified Material Certificate
- _ Other ____________

Assigned to: Technology & Development (School/Laboratory)

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CA—4 (3/76)

A-2042

Quarterly Progress Report

September 1, 1977 to December 1, 1977

ENERGY CONSERVATION STUDY
OF THE
PLATING AND SURFACE FINISHING INDUSTRY

Contract No. EC 77-S-05-5487

Research Project A-2042

AES Research Project #46

Prepared for

Department of Energy

Office of Industrial Conservation

Washington, D. C.

and

American Electroplaters Society

1201 Louisiana Ave.

Winter Park, Florida

by

The Engineering Experiment Station

Georgia Institute of Technology

Atlanta, Georgia

December 1, 1977

INTRODUCTION

The Engineering Experiment Station at Georgia Tech and the American Electroplaters Society are engaged in evaluating energy consumption patterns in the electroplating industry. An engineering analysis of the energy consuming process will result in recommendations to the industry for conserving energy. Twenty electroplating shops will be surveyed, seventeen of which have been chosen and are in some stage of developing an energy profile. Profiles have essentially been completed for two plating shops and they are included in this report. They are referred to by an assigned letter to maintain confidentiality.

RESEARCH ACTIVITIES

Work on the electroplating project commenced September 12, 1977 with the preparation of initial data sheets. These have since been sent to the participating plants, which are being solicited through Mr. Gerry Poll, editor of "Products Finishing" magazine. A strategy meeting was held in October to discuss different ideas for presenting findings. Mr. Jim Voytko representing AES met with program manager, Mr. Rick Wright and principal investigator Mr. Dan Mazzeo. It was agreed that an energy profile would be compiled for each participating shop and that a profile should concentrate on items that are of interest to the industry as a whole.

As of December 1, four completed data sheets have been received, with two more soon to be mailed. An example set of data sheets are included in Appendix C. Plant visits will verify the information provided and allow for further measurements. Plant managers interviewed to date have been especially helpful in providing utility records and plant operating data.

Energy profiles for two plants follow. The first, compiled for Plant C, centers on energy saving items installed in a newly built plant. The second for Plant J, is concerned with potential savings in an older plant and with overall energy usage.

Appendix D contains an article on energy conservation which has been offered for publication in the AES journal, "Plating and Surface Finishing".

Profile Plant C

Plant C is a diverse job shop employing about 35 people. It is a new plant built to replace an aging facility which the company has decided to replace. This plant performs both rack and barrel plating with automated conveyors and some hand operated lines. It is basically a zinc shop with 85% of its work devoted to zinc coatings for corrosion protection. The remaining 15% is mostly nickel and cadmium, performed in the hand operations area. Three lines have been installed in the new facility, which is to receive two others still in the old plant.

In building a new plant, the company management decided that to lower overall operating costs would justify extra capital expenditures. The larger part of this money has been spent on equipment designed to lower energy usage, and so far, it is paying off nicely.

One of the areas where significant savings are showing up is in steam generation and use. The new plant is presently equipped with 3 small boilers of 30hp each, with space available for 2 more of the same size in the future. The steam output from each boiler feeds into a common header with valves arranged to allow isolation of each boiler and of each process line. This arrangement was chosen over installing one large boiler for several reasons.

On a day when all process lines are cold, all boilers can be used for start-up. Once the plant is up to temperature, only one boiler is needed. The others are shut down and valved off from the steam header. One small boiler tends to cycle less than one large one, loses less heat and therefore is 3-5% more efficient than operating one large boiler, once the plant is warm. If, when the plant is cold, it is desired to start-up just one solenoid valve to regulate steam flow. These units are far less expensive than more sophisticated modulating valves but are very satisfactory for the service. They have been installed without by-pass valves. The purpose of this is to insure that the units are repaired immediately when they break down. Either they work, or they do not. A by-pass valve cannot be used to feed steam to the tank, wasting energy due to poor control. Plant managers feel that this item saves a great deal of energy.

Other changes have been instituted in the new plant. Surface cleaning is now done with liquid caustic cleaners instead of with powders containing sodium carbonate. The amount of sludge removed from the tank is far less, as is the amount of cold water needed to replenish any pair of cleaning baths. The same solution is used in both soak cleaner and as electro-cleaner which overflows one into the other, the soak being the first wash. Average cleaning solution temperatures have been lowered to 105°F, whereas with powdered cleaners average temperatures were 190°F, indicating significant savings.

Using liquid caustic can have other advantages. At Plant C it is stored in tanks outside the building and is pumped in when needed. This eliminates safety problems associated with handling carboys in the plant. Less sludge and lower water consumption mean less waste treatment. In this facility liquid cleaners produce excellent results with lower operating costs.

Electrical energy consumption has been reduced drastically, achieved with a corresponding reduction in the number of rejects. Zinc plating in the old shop was done with cyanide baths. The new shop uses chloride solutions, which are more demanding. Air agitation especially must be well controlled, but the benefits are worth it. A barrel plating line in the old shop consumed 6000 amps DC at 18 volts. The replacement line in the new shop performs the same duty, on the same amount of material and consumes 3000 amps at 12 volts. This is a reduction in power consumed of 67%. A rack plating line in the old shop consumed 5500 amps at 6 volts. The new line consumes 2500 amps at 3 volts, a reduction of 77%. This has been accompanied by a change in rejected products from 17% to 1%! The reason for this is the ability of the chloride baths to perform well on long parts where current density drops along the length of the part. Cyanide solutions just did not perform as well.

Lighting in the new shop is done with sodium vapor lights, which in addition to being more efficient than conventional lighting, help to illuminate defects. Another good idea employed in this shop is the use of infrared heating stations for personal comfort during cold months. The ventilation system moves 95,000 CFM through the plant at full capacity. The cost to keep the entire shop heated would be very high. The problem is circumvented by using infrared heaters to warm a small area central to the employees' working area.

Plant management expects utility bills in the new shop to be 50% of what they were in the old shop. Construction of the 2 additional plating lines is expected to be complete in January '78. A subsequent report will document the actual savings in utilities by comparing the old shop in its last 3 months of full operation, January, February and March of 1977 to the same months for the new shop in 1978. This will be a most interesting comparison.

To summarize then, plant C has implemented the following energy conservation items:

1. Small, individual boilers.
2. Return of all steam condensate.
3. Insulation of all steam and condensate piping.
4. Use of flow limiting non-constant orifice valves on all water inlets.

5. Solenoid temperature control valves on steam lines heating all baths, installed without by-passes.
6. Surface cleaning with lower temperature liquid caustic baths.
7. Replacement of cyanide solutions with higher efficiency chloride baths in zinc plating.
8. Sodium vapor lamps.
9. Individual infrared heating stations.

Plant utility bills indicate very substantial savings. These will be quantified in the above mentioned comparison in a subsequent report.

Profile Plant J

Plant J is an older facility that employs about 35 people. It is a diverse job shop with both rack and barrel plating lines. Most of the work is hardware plating done with conveyors and some hadn operated lines. Zinc and nickel account for about 95% of the metals plated with several other metals consumed in much smaller amounts including chrome, cadmium, silver and tin. A new barrel plating line intended for low cyanide zinc plating has just become operational.

Several rinses and baths operate well above room temperature and thus require heating. Steam is the primary medium for tank heating, with coils installed in each tank in a conventional manner. Electric resistance heaters have been installed for use during periods of gas curtailment and thus are only used once or twice a year. Natural gas is the only fuel burned in one fire-tube boiler which has been in operation for several years. The boiler is set to produce steam at about 90 psi, firing at 86 psi and shutting down at 94 psi. Plant managers have noticed that as equipment has been added, the boiler cycle time has grown shorter and the time needed to heat-up from a cold start has grown longer. With the addition of the new zinc plating line, the boiler may now be somewhat short of capacity.

On a recent plant visit, during the day shift, all lines were in operation. The boiler ran constantly and could only produce steam at 66 psi. This indicates potential problems during colder weather. The boiler produces approximately 3489 lbs/hr. of steam under these conditions and consumes about 5.1 million BTU/hr to do it (see Appendix B). Condensate is not returned from any part of the plant. Condensate return alone would save, conservatively, 10% of the natural gas used. In addition approximately 6600 gal/da of water would be saved, lowering water and sewer charges and resulting in a total annual savings of $5,165/yr.

The combustion efficiency of the boiler was checked on a recent plant visit by sampling the stack gases (see Appendix B). The efficiency was found to be about 80.6% and assumes complete combustion. This was checked by visual inspection of the exit gases, flame pattern and color. An increase in efficiency of about 1% could be achieved by adjusting the excess oxygen down to about 2% by volume. This may be difficult with a boiler of this type and would require closer attention in the interest of safety, but it has been done before successfully.

Improved maintenance is one of the new goals of the plant managers. This is a step in the right direction in improving overall energy efficiency. Insulation on steam lines, for example, is in poor repair. Several steam leaks exist in distribution piping at unions, valves and other fittings. Steam traps are not inspected at regular intervals and should be to insure proper operation. They are checked only when an obvious problem exists. A check of the amount of uninsulated pipe, the number of steam leaks and the number of steam traps in the plant shows that these items would contribute conservatively, 1-2% each toward lowering overall energy consumption. This would yield an overall total of about 5%. This plant should concentrate on these basic items.

Additionally, limiting water consumption in the heated rinse tanks of each process line proivdes an excellent opportunity to save energy. Presently, all inlet water lines are manually controlled, allowing for wide variations in fresh water input. Plant managers have attempted to reduce water consumption by indoctrinating plant employees, without a great deal of success. The past five monthly water bills show a 4% fluctuation in usage, with an average of about 3.5 million gallons per month. This equates to about 150 gpm consumed during operating hours, most of which is used in heated cleaning and rinse tanks. The remainder is used in heated cleaning and rinse tanks. The remainder is used in the boiler (7gpm), in replacing water lost to evaporation and used domestically. The latter two uses are relatively small, consuming perhaps 5 gpm. Some water is used in cooling, but is often reused as rinse water. This leaves approximately 138 gpm used in heated rinses and cleaning baths at an average temperature of about 175°F. A reduction in water flow to these tanks is surely feasible, by installing individual water stations at each tank and equipping each with flow limiting valves (some tanks already have individual water stations.) The amount saved depends on establishing a minimum flow rate to each tank.

Plant Electrical

Plant J electrical usage falls into the following four categories:

1. Rectifier consumption-plating
2. Lighting
3. Electrocleaning
4. Electric motors - pumps, fans etc.

The first, rectifier consumption, will be estimated by applying Faraday's law, knowing the amount of metal consumed annually. Some assumptions will have to be made concerning overall current efficiencies. The second, lighting, will be estimated knowing the number of lights, the wattage of each and the fact that they are always on, mainly for security reasons. The third, electrocleaning, will be estimated from the known applied voltage, current and an estimate of the time in use. The fourth, electric motors will be estimated by difference knowing the total annual usage of 1.5 million kwhs. Annual rectifier consumption is estimated at about 410,000 kwhs on 27% of the total (see appendix B). Lighting is estimated at 65,000 kwhs or 4.0% of the total. Electrocleaning is estimated at 60,000 kwhs or 4.0% of the total and electric motors consume 9.7×10^5 kwhs or 65% of the total.

APPENDIX A

Manufacturers for Equipment installed in Plant C

1. Non-constant orifice valves, "Dole" valve.

   Eaton Manufacturing
   Controls Division
   Carol Stream, Ill.

2. Infrared Heaters

   Perfection I. R.
   Waynesboro, Ga.

3. Temperature Controllers; with standard solenoid

   Cleveland Process Co.
   Cleveland, Ohio

4. Information on Chloride baths available from

   Harshaw Chemical Co.
   Cleveland, Ohio

APPENDIX B

Data and Calculations

Plant C

Condensate savings estimated from boiler name plate data and observed running characteristics.

Name plate data

Cyclotherm 30 hp

Maximum steaming rate 1035 lbs/hr

Maximum working pressure 15 psi

Heating surface 90 ft^2

On a typical day one boiler runs at maximum fire an average of 37% of the time, therefore; .37 (1035 lbs/hr = 383 lbs/hr actual steam produced. Assume the condensate returns to the boiler at 205^oF, then

$(383\ ^{lbs}/hr)\ 1\ BTU/lb^oF\ (205^o - 60^o) = 56000\ BTU/hr$

saved by returning condensate, the value of which is, assuming an 80% boiler efficiency

(56000 BTU/hr) (16 hrs/da) ($1.83/MM BTU) (1/.80) = $2.05/da saved.

The value of the water saved is (383 lbs/hr) (16 hrs/da) (1 gal/8.34 lbs) $.504/M gal) = $.37/day

for a total savings of $2.42/day or $692/yr including sewer charges. Pipe insulation savings are estimated by calculating the difference in heat loss between the insulated and uninsulated pipe.

$Q = \Delta\ U\ A\ \Delta\ T$

for 15 psi service and 60^o avg room temperature

Δ T is $245^o - 60^o = 185^oF$

A is approximately (2π 1/12) 700'

Δ U is 2.65 - .25 = 2.40 $BTU/ft^2\ ^oF$) =

$Q = (2.4\ BTU/ft^2\ ^oF\ hr)\ 366\ ft^2\ (185\ ^oF) =$

163,000 BTU/hr

Assume a more conservative figure of 150,000 BTU/hr to offset errors in approximating the length of pipe and thus the area A.

The value of this savings is approximately

#5.95/da or \$ 1700/yr.

Plant J

The following combustion data were recorded by stack gas sampling and analysis

Sample	1	2
Gas Temp ^{o}F	430 ^{o}F	430 ^{o}F
Percent CO_2	7½ %	9½ %
Percent O_2	5½ %	5%
Combustion Efficiency	80%	81¼ %

Estimate the overall boiler efficiency as 78% for use in further calculations.

Boiler Nameplate data

Manufacturer: Cyclotherm

Maximum Steaming Rate 3450 lbs/hr

Maximum Working Pressure 125 psi

Heating surface 306 ft^2

The boiler will produce slightly more steam at 66 psi than at the rated pressure of 125 psi. An enthalpy balance shows this amount to be

(3450 lbs/hr) (1191 BTU/lb) = (X lbs/hr) (1179 BTU/lb)

X = 3484 lbs/hr @ 66 psi

Inlet water is about 60^{o}. If all condensate were returned at $200^{o}F$ the BTU's saved are: (3484 lbs/hr) (1 BTU/lb ^{o}F) (200 - 60) = 4.9×10^5 BTU/hr

with a 78% boiler efficiency, the value is:

(4.9×10^5 BTU/hr) (1/.78)(\$1.33/MM BTU) = \$.83/hr

or \$3400/yr.

The value of the water saved is:

(3484 lbs/hr) (1gal/8.34 lbs) (16 hr/da) = 6600 gal/da

(6600 gal/da) (\$.00104/gal) = \$6.85/da or

\$1765/yr including sewer charges

Additional savings may be reaped from lower use of boiler chemicals.

Electrical Usage

Apply Faraday's Law in the following form:

$$\text{grams deposited} = \frac{\text{Molecular Wt X Energy consumed (calories)}}{\text{Molar equivalent X } 23{,}060 \ \frac{\text{cal}}{\text{volt e.g.}} \text{ X voltage applied}}$$

For example zinc:

$$(36{,}000 \text{ lbs})\ 454 \text{ grams/lb} = \frac{65.4 \text{ X (calories)}}{2 \text{ X } 23{,}060 \text{ X } 7.5}$$

Where 7.5 volts is the average applied, half at 3 volts rack plating and half at 12 volts barrel plating. This is the approximate work distribution. The calories delivered are then

8.6×10^{10} cals

assuming a 72 percent overall efficiency for rack plating and 40 percent for barrel plating and converting to kwhs:

$$8.6 \times 10^{10} \text{ cals } \frac{2}{(.72 + .40) \text{ eff}} \times 1.16 \times 10^{-6} \text{ kwhs/cal} =$$

1.75×10^{5} kwhs consumed.

The following table summarizes these calculations

Metal	Pounds	Current Efficiency Used	Kwhs Consumed
Zinc	36,000	56% average	1.75×10^{5}
Nickel	26,000	72%	6.7×10^{4}
Chrome	3,000	12%	1.67×10^{5}
Cadmium	500	60%	540
Tin	500	75%	615
Copper	100	50%	190
		TOTAL	4.1×10^{5} kwhs

Plant lighting totals about thirty, 150 watt conventional bulbs and seventy-four, 40 watt flourescent bulbs for a total wattage of about 7,460 watts operating essentially 8,760 hours/yr. The consumption is then:

$$7{,}460 \text{ watts X } 8{,}760 \text{ hrs X } \frac{1 \text{ kilowatt}}{1{,}000 \text{ watts}} = 65{,}000 \text{ kwhs.}$$

Electrocleaning energy consumption averages for six cleaning stations as follows:

300 amps @ 6 volts	120 hrs/wk
1000 amps @ 7 volts	80 hrs/wk
250 amps @ 6 volts	40 hrs/wk
250 amps @ 4 volts	10 hrs/wk
1000 amps @ 9 volts	25 hrs/wk
500 amps @ 6 volts	25 hrs/wk

This totals to an annual consumption of about 60,000 kwhs.

By difference then, electric motors consume:

$$1.5 \text{ x } 10^6 - (4.1 \text{ x } 10^5 + .65 \text{ x } 10^5 + .60 \text{ x } 10^5) = 9.7 \text{ x } 10^5 \text{ kwhs.}$$

APPENDIX C

Example Data Sheets

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332
GEORGIA PRODUCTIVITY CENTER

Gentlemen:

As you are aware, we at Georgia Tech are to survey approximately 20 of your electroplating plants. The purpose is to:

1) Identify energy consuming operations.

2) Define the amount and mechanisms of energy usage.

3) Develop energy saving modifications.

4) Define the energy saving potential for each operation.

5) Disseminate all information through AES.

We will need your time and cooperation in order to meet our purpose. In return, we intend to present you with economically viable energy saving ideas and process modifications.

A visit to your plant should take 1 - 2 days, during which time we will need the assistance of knowledgeable plant personnel to answer our questions and to help in collecting data. We want to point out that your company is not liable for any accidents or injuries; we are covered by our own insurance.

Enclosed is an extensive procedures list that will give us much of the data we need to complete the survey. Completion of this list will minimize your time and expense needed during our plant visit. It is to be expected that not all of the requested data is applicable to every shop. Use your judgement in omitting data, but we strongly suggest your add pertinent information that is not requested.

Sincerely,

Daniel A. Mazzeo
Assistant Research Engineer

DAM/pat

Procedures List

Energy Usage Breakdown - Outline

I Electroplating Consumption

II Process Heat

III Process Electrical

IV Domestic Heating & Ventilation

V Waste Disposal

VI Pollution Control

VII Miscellaneous Data

Please feel free to use the extra space provided and attach additional sheets if necessary.

I. Electroplating Energy Consumption

a) Annual power consumption for electroplating ______________ kilowatts

b) Pounds of anode metals consumed annually

1. Nickel ______________ lbs.

2. Chromium ______________ lbs.

3. Copper ______________ lbs.

4. Cadmium ______________ lbs.

5. Silver ______________ lbs.

6. Gold ______________ lbs.

7. Other ______________ lbs., etc.

c) Square feet of aluminum anodized annually

1. Sulfuric acid anodized ______________ ft^2

2. Chromic acid anodized ______________ ft^2

3. Other ______________ ft^2

d) Rectifiers

1. input/output ______________ efficiency ______________ %

2. input/output ______________ efficiency ______________ %

3. input/output ______________ efficiency ______________ %

4. input/output ______________ efficiency ______________ %

j) List ovens and dryers and operating temperature

Power Capacity (Kw)	Operating Temp.	Time in operation per year
1.		
2.		
3.		
4.		
etc.		

k) List any heated cleaners, vapor degreaser, etc., and note energy consumption

	BTU/yr	Kwh/yr
1.		
2.		
3.		
etc.		

III. Process - Electrical

a) List pump motors and HP, operating load percent, and annual operating hours

1.

2.

3.

etc.

b) Capacity for refrigeration for anodizing and other process cooling. ____________________ BTU's or Tons.

c) Conveyors and crane motors HP, operating load percent and annual operating hours.

1.

2.

3.

d) Mechanical mixers HP, operating load percent and annual operating hours.

1.

2.

3.

e) Compressed Air usage total HP ______________________________.

f) Bath filters total HP ____________________________________.

IV. Space Heating and Ventilation

a) List space heating equipment, heat source, electrical, steam, gas, etc.

1.

2.

3.

b) List AC units and cooling capacity of each

1.

2.

3.

c) List motors and HP of air moving fans, ventilators, blowers, etc.

1.

2.

3.

Include estimate of loading percentage and annual hours of operation.

V. Waste Disposal - Pollution Control

Do you use energy and how much in the following operations; note BTU's and all HP involved.

1. Flocculating ______________
2. Filtering ______________
3. Clarifying ______________
4. Reverse Osmosis ______________
5. Evaporators ______________
6. Incinerators ______________
7. Scrubbers ______________
8. Cyclones ______________
9. Baghouses ______________
10. Other ______________________________

IV. Miscellaneous data

a) How large is the shop area? (sq. ft.) ______________

b) Type of lighting used and wattage? __________ ______________

c) Cost per kwh ______________

Please add any other pertinent information.

APPENDIX D

The following article has been offered to AES for publication in their journal "Plating and Surface Finishing." It is intended to generate interest and offer helpful suggestions. The reference used in writing this article is suggested for further details on this subject. It is:

"Energy Conservation Program Guide for Industry and Commerce"

NBS Handbook 115.

Getting Energy Conservation off the Ground Floor

The first task in implementing an energy conservation program is organizing human resources, bringing people together to accomplish a goal. This is important in establishing responsibilities and coordinating work,especially in a large shop where procedures are more formal. If the mechanics set up now do not work well the program can fail. Hopefully, the following ideas and suggestions will aid in getting things underway.

Get Upper Management Committed - this is the most important single element to a successful program. The company management can marshall their people and resources once they are sold on energy programs. Show them examples of where energy and money can be saved. Convincing upper management that money spent on energy conservation is well invested will mean a great deal in achieving a reduction in energy usage.

Decide on a Leader - Every good program has a focal point, a director, a person with ultimate responsibility for getting the work done. So it is with energy conservation. He or she must have several basic resources as a minimum for attaining success. These include, a working knowledge of the plating shop, a rapport with employees at all levels within the company and the authority to initiate change, either in the way the process is operated or in plant equipment. Major expenditures, of course, need upper management approval. The energy conservation director needs access to all levels of management.

Time allotment can be a problem especially in a small shop where the person in charge of energy conservation will have other duties. It need be recognized that this project will take some time and unless the shop is large enough to make this a full time job, other duties need be given a lower priority or temporarily be made another's responsibility.

Form an Energy Conservation Committee - The committee should have a representative from each department. It needs to investigate energy problems, analyze them, find economic solutions and implement them. It should publicize results company wide. The committee should meet on a regular basis in order to keep everyone informed and keep projects moving. Committee meetings need not be long but need to be held. Missing a meeting or two is one way to lose momentum and fall behind.

Set a Goal, Time Limit and an Acceptable Rate of Return - A ten percent reduction in one year is not unreasonable for many plating facilities, so long as the expected rate of return is not too high. A three to four year limit or payback period will generate many worthwhile projects with several in the one to two year range.

Consider Incentives - Offer a reward for the best energy saving idea. It need not be elaborate or expensive. Tickets to a ball game or dinner at a local restaurant. This will help foster employee participation. Good ideas often come from concerned employees.

Extoll the Virtues of Energy Conservation - Let everyone know that saving energy is financially good for both the country and your company. It helps strengthen job security and will contribute to America's energy independence.

Publicize Your Efforts - Let committee proceedings be known. Use the available means to keep people informed, posters, the bulletin board, word of mouth etc. Consider hiring an artist to create your own energy conservation posters. Put employee ideas on these and really boost morale!

Re-educate People at All Levels - The drastic increase in energy costs over the last few years has given rise to new economics. The old rules of thumb no longer apply, for instance, allowing an electric motor to continue running may no longer be cheaper than turning it off and restarting it later depending on the motor size and the time involved.

Not all of these suggestions will be helpful but some are necessary for everyone. In the small plating shop energy conservation may largely be a one man job. It is still a good idea to involve others especially if they have an interest. Two heads can be better than one.

A-2042

Quarterly Progress Report
December 1, 1977 to March 1, 1978

ENERGY CONSERVATION STUDY OF THE PLATING AND SURFACE FINISHING INDUSTRY

Contract No. EC 77-S-05-5487
Research Project A-2042
AES Research Project #46

Prepared for
Department of Energy
Office of Industrial Conservation
Washington, D,C.

and

American Electroplaters Society
1201 Louisiana Ave.
Winter Park, Florida

by

The Engineering Experiment Station
Georgia Institute of Technology
Atlanta, Georgia

March 1, 1978

INTRODUCTION

The Engineering Experiment Station at Georgia Tech and the American Electroplaters Society are engaged in evaluating energy consumption patterns in the electroplating industry. An engineering analysis of the energy consuming process will result in recommendations to the industry for conserving energy. Twenty electroplating shops will be surveyed, all of which have been chosen and are in some stage of developing an energy profile. Profiles have essentially been completed for seven plating shops and they are included in this report. They are referred to by an assigned letter to maintain confidentiality.

RESEARCH ACTIVITIES

Work on the electroplating project has continued with very good response from participating plants. Twenty plants are actively participating with several others available if needed. A meeting of AES representatives, Jim Voytko, Gerry Poll and Warren Doty with Georgia Tech project staff Dan Mazzeo and Rick Wright, held in early December, helped to define the direction of the project. A similar meeting is planned for late March to review the project and its goals.

Energy profiles have been completed for seven plants. Plants may be categorized broadly in terms of energy usage. Plants using large amounts of energy primarily plate zinc, copper, nickel and chrome for decorative purposes and corrosion protection. Plating consumes from 20% to 55% of their electrical energy. The one anodizing shop surveyed thus far has also been included in this group:

The average electrical energy consumption for these plants is:

1. Plating	38%
2. Lights	14%
3. Electrocleaning	6%
4. Motors (as below)	42%
Exhaust fans	15%
Filters	5%
Blowers, air agitator, dryers, boiler, etc.	6%
Pumps (all)	5%
Hoists and drives	4%
Other	7%
	100%

Average process heat energy consumption is:

Dryers and ovens	8.1%
Space Heat	7.8%
Process tanks	31.4%
Rinses and cleaners	23.9%
Boiler losses	22.0%
Other	6.8%
	100%

The second type of plant typically plates parts that are small in size. Plating consumes around 1% of the electrical energy consumed. Plating tanks are much smaller and are heated electrically, whereas plants in the large energy usage group heat via steam. It is worth noting that only one of the small energy usage plants has been surveyed to date. Thus, other seemingly significant energy use characteristics discussed until substantiated with subsequent data.

Appendix A, which follows, contains energy profiles for the seven facilities surveyed thus far. Appendix B contains example calculations.

The article, "Getting Energy Conservation off the Ground Floor", included in the previous quarterly report, is now scheduled to be published in the AES journal "Plating Surface Finishing".

APPENDIX A

PLANT ENERGY PROFILES

Plant A Energy Profile

Note: Plant A is unique for two reasons:

1) The work plated is small in size compared to other shops.
2) All process heating is done electrically, natural gas is used only for building heat in winter months, and for domestic purposes.

Electrical Energy Usage Breakdown

Total annual kilowatt hours 1.18×10^6

		Percent of total
1.	Plating	.9
2.	Lights	16.3
3.	Cracking Furnace	3.4
4.	Tank Heat	50.0
5.	Exhaust Fans	10.4
6.	Filter and liquid pumps	3.7
7.	Air compressors	5.8
8.	Vapor Degreasers	3.5
9.	Barrel and Tumbler drives	2.4
10.	Lab Equipment	2.9
11.	Hoists	.7
		100.0%

Process Heat Energy Usage Breakdown

Total natural gas usage 1977 approximately 59000 therms, 98.4 percent of which was consumed in plant heating. The remaining 1.6 percent was consumed in heating water for domestic use.

Plant D Energy Profile

Electrical Energy Usage Breakdown

Total annual kilowatt hours 4.95×10^6

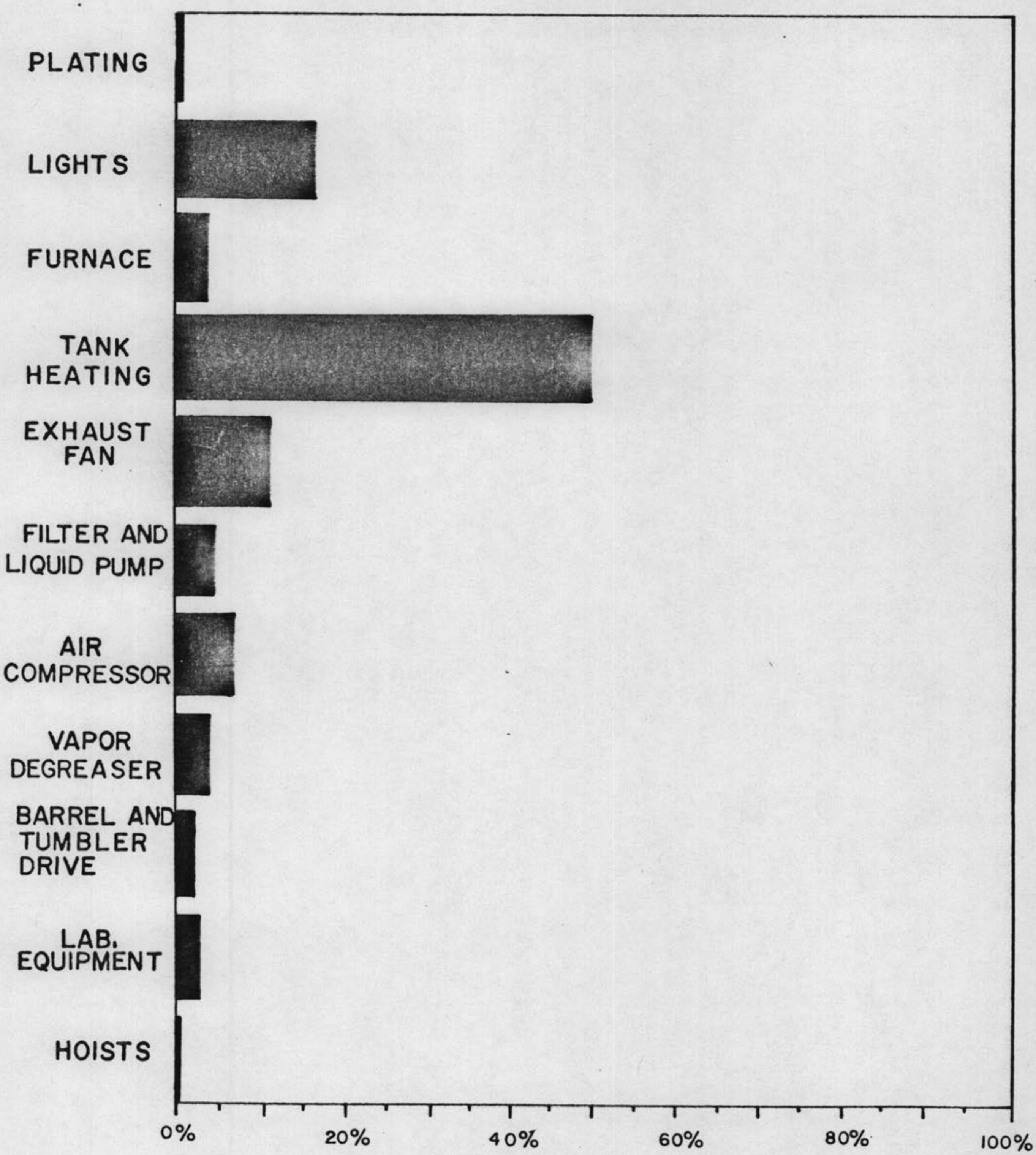
		Percent of total
1.	Plating	54.1
2.	Lights	8.5
3.	Electrocleaning	1.8
4.	Buffing	3.0
5.	Exhaust fans	19.1
6.	Filters	2.3
7.	Blowers: Dryers, Air agitation, boiler	4.4
8.	Pumps recirculating	2.2
9.	Waste treatment pumps	2.4
10.	Drives and Lifts	2.2
		100.0%

Process Heat Energy Usage Breakdown

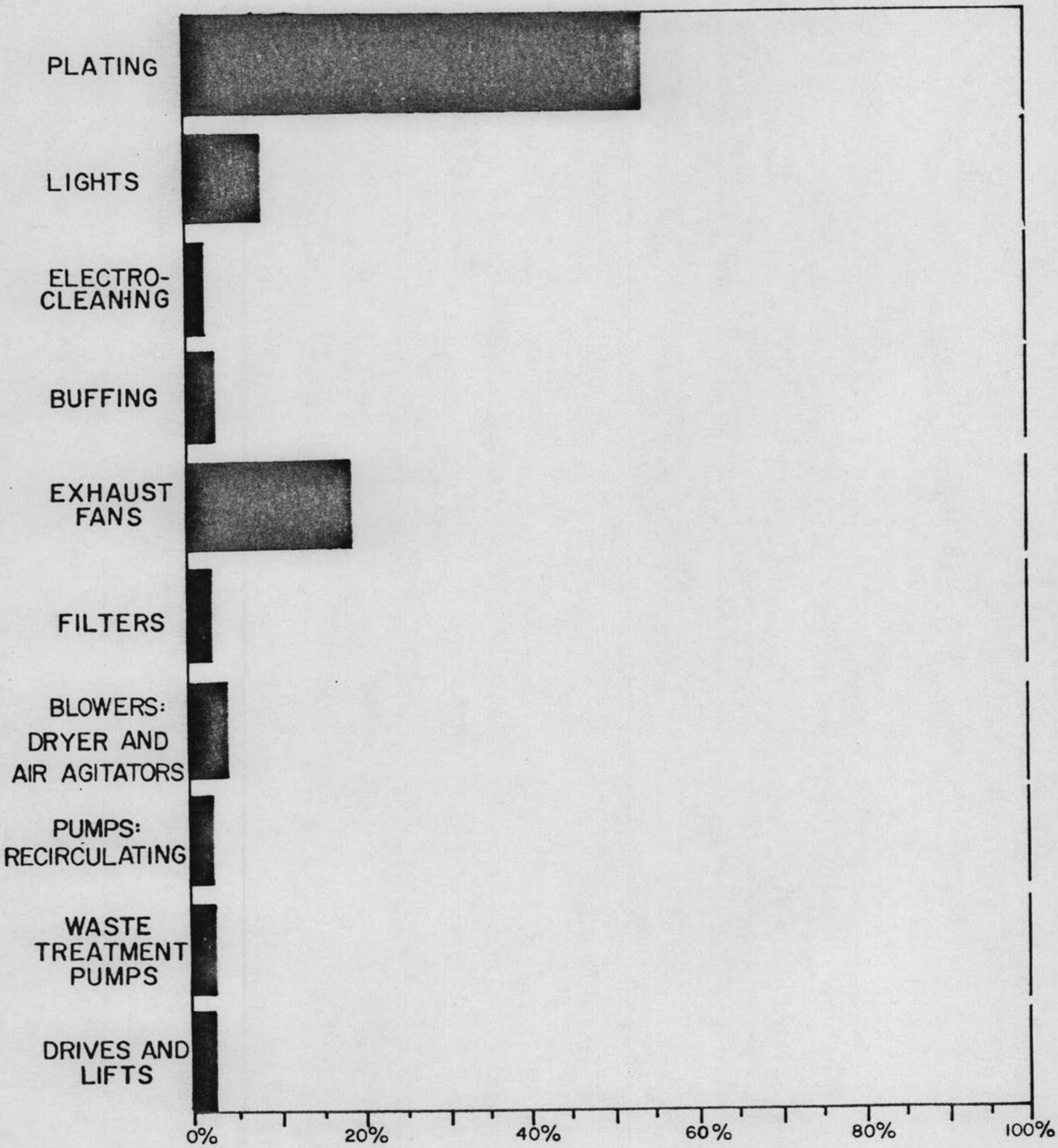
Total annual BTU's 1.49×10^{11}

		Percent of total
1.	Dryers	9.9
2.	Process and electrocleaning tanks	60.4
3.	Rinses and cleaners	13.2
4.	Vapor degreasers	.3
5.	Boiler losses	16.2
		100.0%

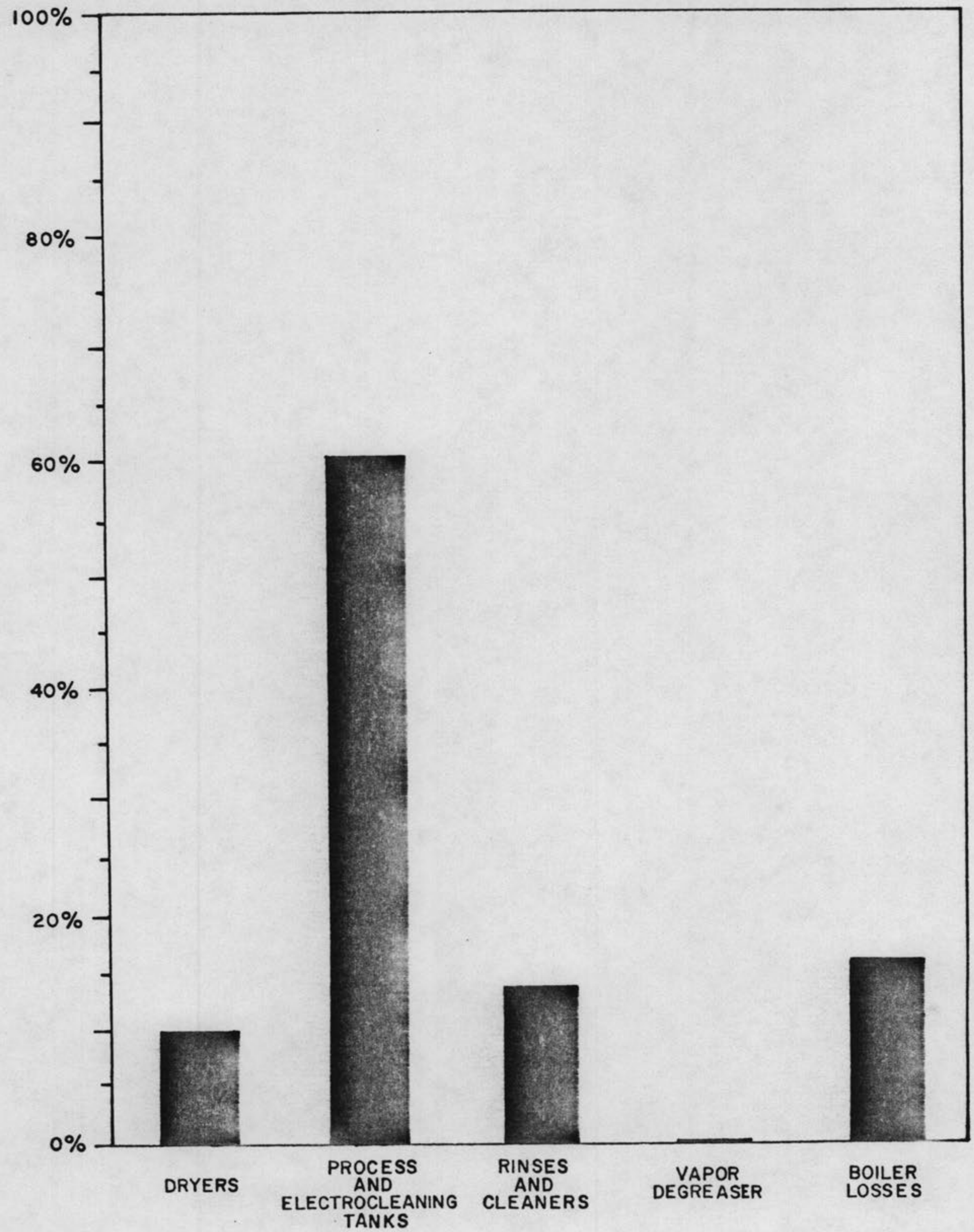
BREAKDOWN OF ELECTRICAL USAGE IN PLANT A



BREAKDOWN OF ELECTRICAL USAGE IN PLANT D



BREAKDOWN OF PROCESS HEAT ENERGY USAGE IN PLANT D



Plant E Energy Profile

Electrical Energy Usage Breakdown

Total annual kilowatthours 5.75×10^5

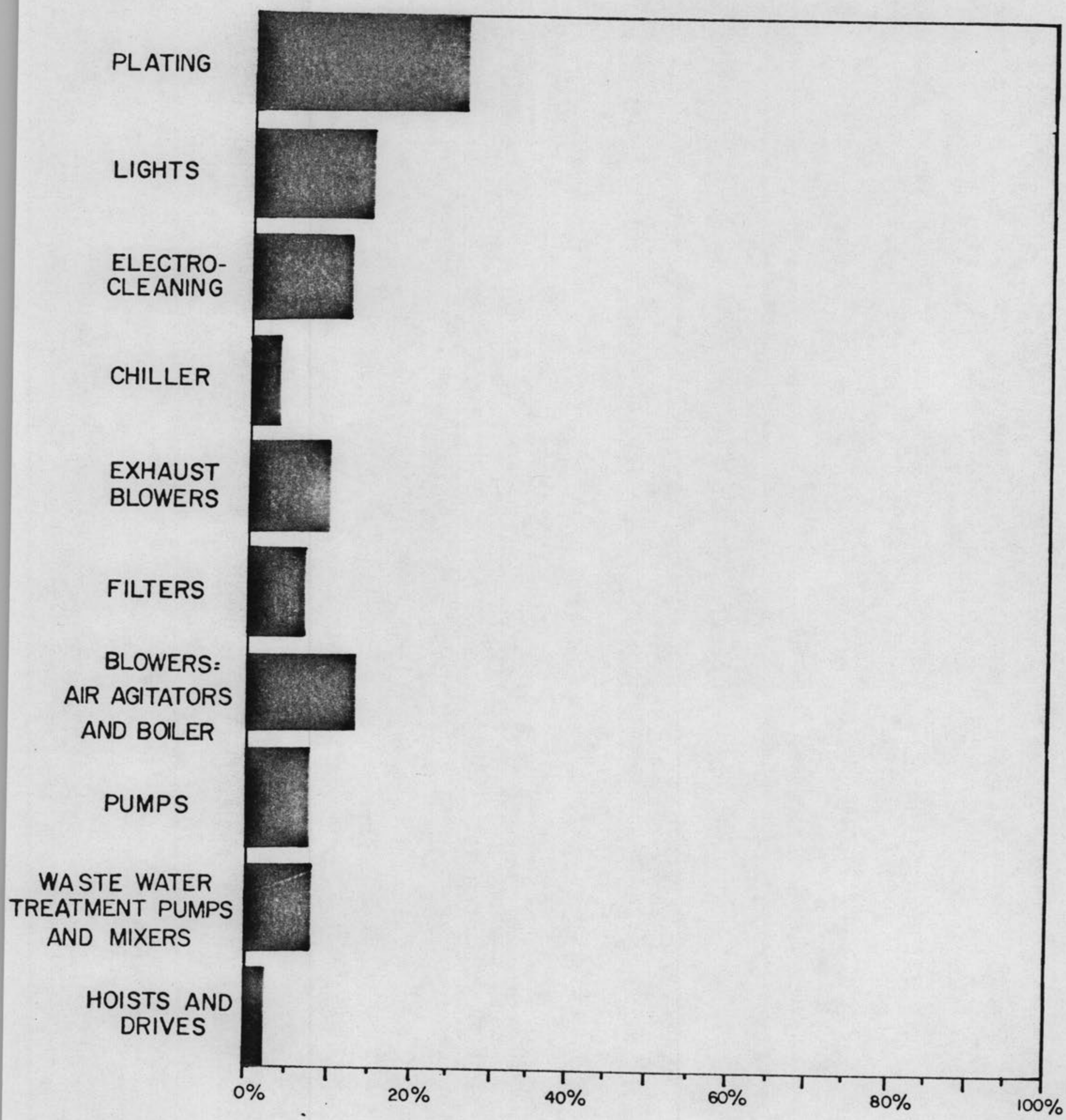
		Percent of total
1.	Plating	25.7
2.	Lights	14.3
3.	Electrocleaning	11.3
4.	Chiller	3.2
5.	Exhaust fans	9.8
6.	Filters	6.1
7.	Blowers; air agitation and boilers	13.5
8.	Pumps	6.8
9.	Waste treatment pumps and mixers	7.0
10.	Hoists and drives	2.4
		100.0%

Process Heat Energy Usage Breakdown

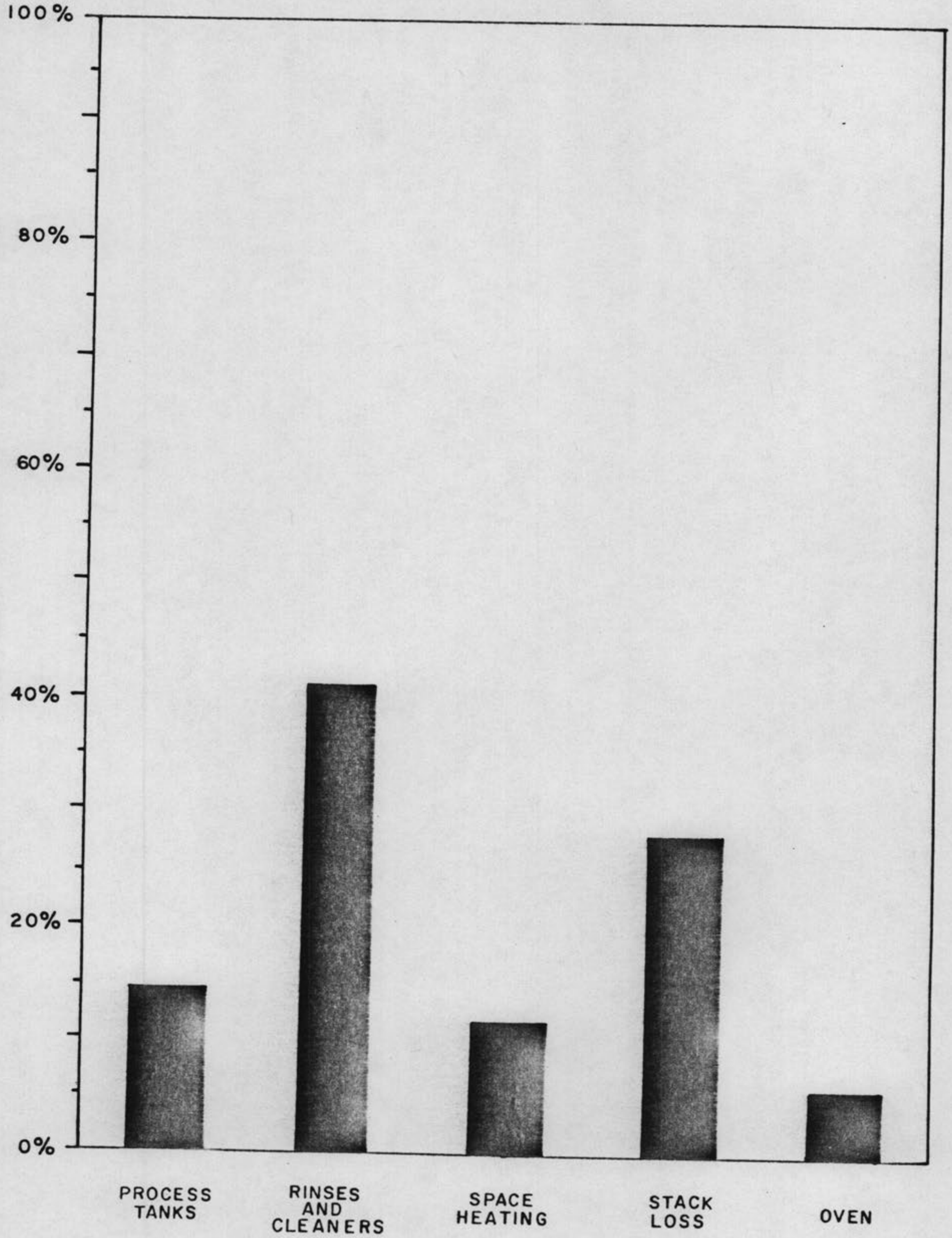
Total annual BTU's 1.05×10^{10}

		Percent of total
1.	Process tanks	14.3
2.	Rinses and cleaners	41.0
3.	Space heating	11.4
4.	Stack loss	27.6
5.	Oven	5.7
		100.0%

BREAKDOWN OF ELECTRICAL USAGE IN PLANT E



BREAKDOWN OF PROCESS HEAT ENERGY USAGE IN PLANT E



Energy Profile Plant F

Electrical Energy Usage Breakdown

Total annual kilowatthours 3.03×10^5

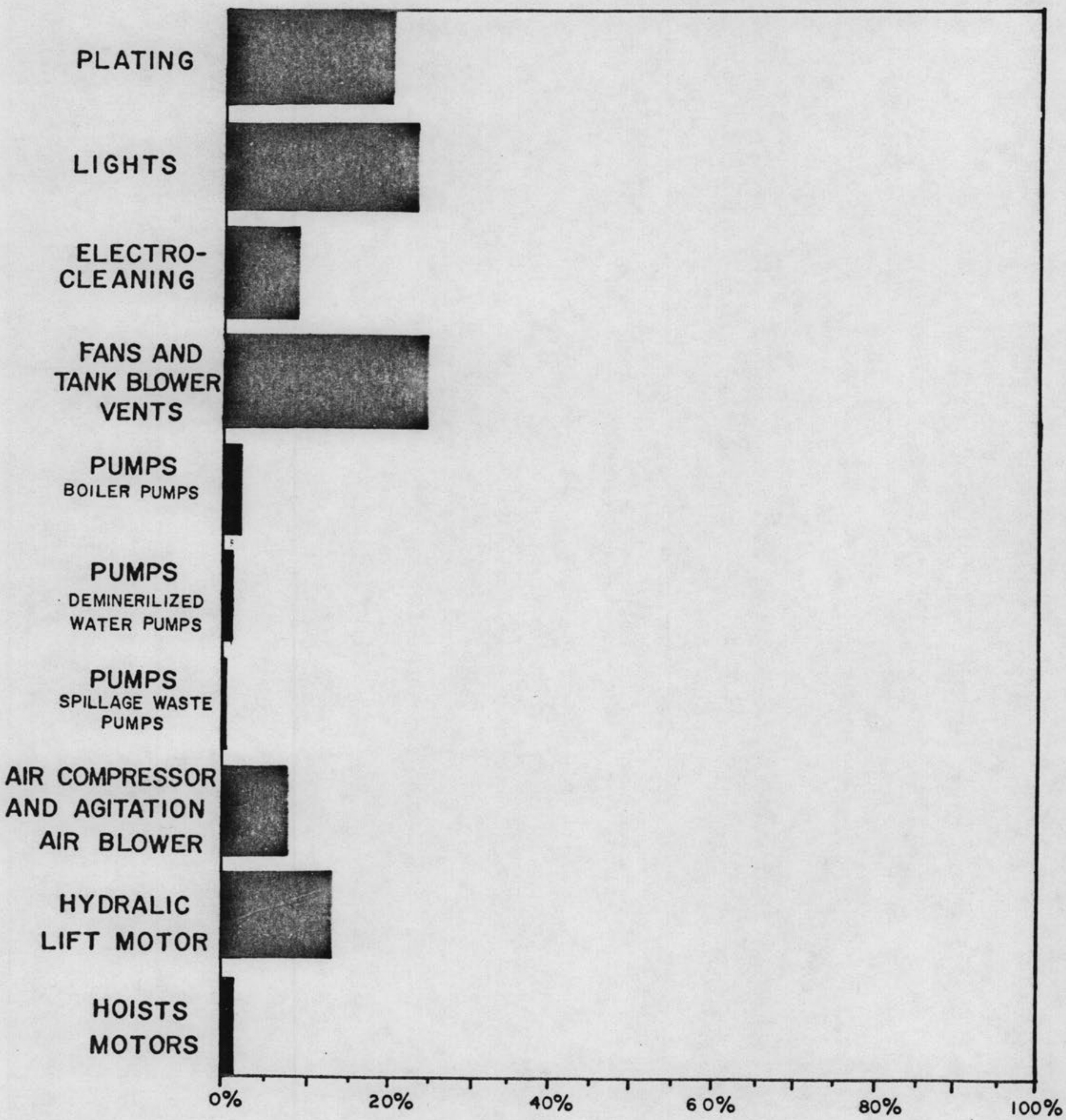
		Percent of total
1.	Plating	20.0
2.	Lights	23.0
3.	Electrocleaning	8.0
4.	Exhaust Fans	24.7
5.	Boiler pumps	2.0
6.	Demineralized water pumps	1.0
7.	Spillage waste pumps	.2
8.	Air compressor and agitator blowers	7.4
9.	Hydraulic lift motor	12.4
10.	Hoist motors	1.3
		100.0%

Process Heat Energy Usage Breakdown

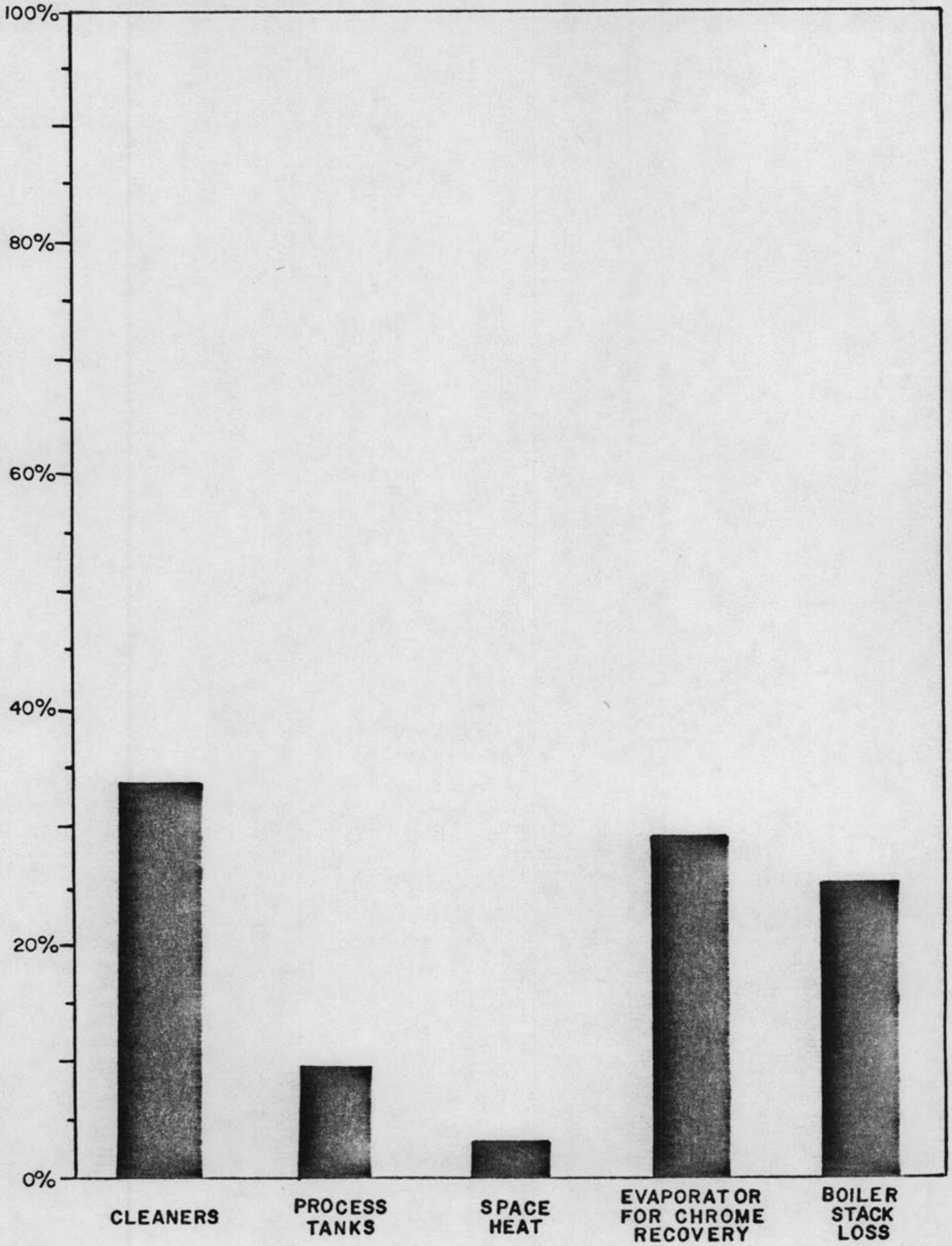
Total annual Btu's 1.51×10^{10}

		Percent of total
1.	Cleaners	33.7
2.	Process tanks	9.6
3.	Space heat	2.7
4.	Evaporator for chrome recovery	28.9
5.	Boiler stack loss	25.1
		100.0%

BREAKDOWN OF ELECTRICAL USAGE IN CHROME SHOP F



BREAKDOWN OF PROCESS HEAT ENERGY USAGE IN PLANT F



Energy Profile Plant G

Electrical Energy Usage Breakdown

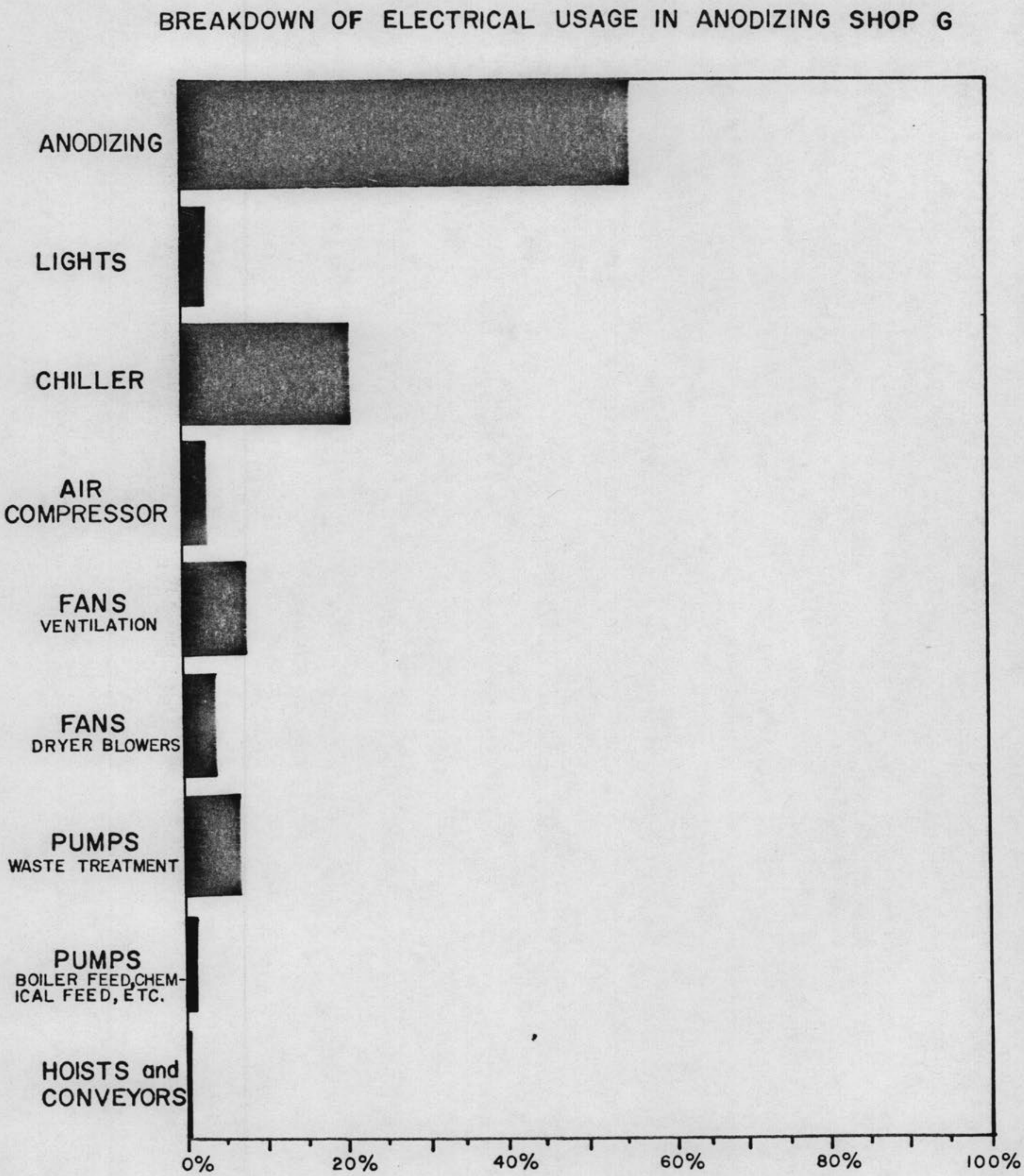
Total annual kilowatthours 4.45 x 10^6

	Percent of total
1. Anodizing	55.0
2. Lights	2.0
3. Chiller	20.0
4. Air compressor	2.5
5. Exhaust fans	8.0
6. Dryer Blowers	4.0
7. Waste treatment pumps	7.0
8. Boiler feed, chemical feed pumps	1.0
9. Hoists and conveyors	.5
	100.0%

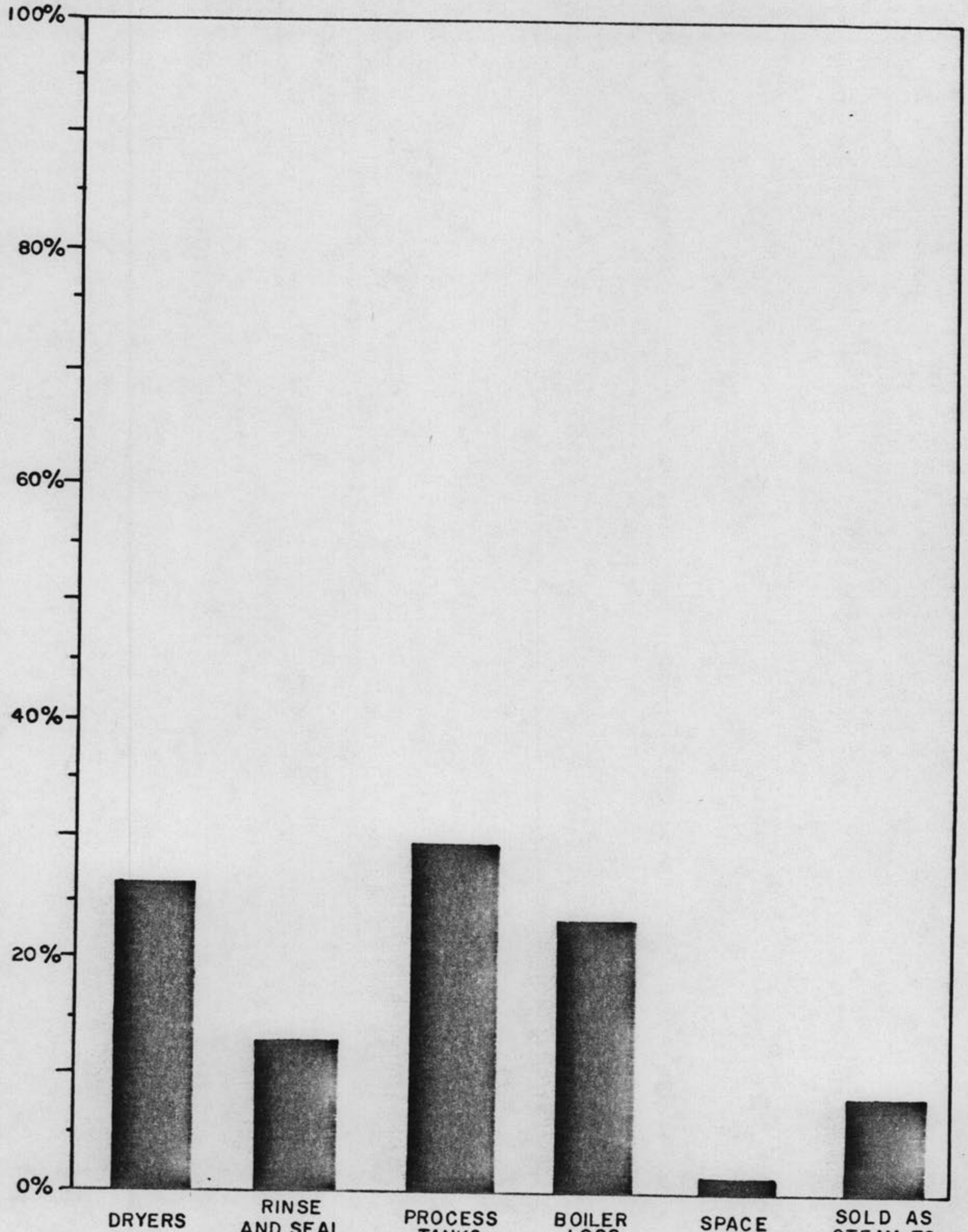
Process Heat Energy Usage Breakdown

Total annual BTU's 6.53 x 10^{10}

	Percent of total
1. Dryers	
a. Gas	7.2
b. Steam	19.1
2. Tank heating	42.0 (as below)
a. Rinses	1.5
b. Cleaners	1.5
c. Brightners	25.7
d. Acetate	2.3
e. Seal water	11.0
	42.0%
3. Boiler loss	23.2
4. Space heat	1.0
5. Sold as steam to adjoining firm	7.5
	100.0%


BREAKDOWN OF ELECTRICAL USAGE IN ANODIZING SHOP G
ANODIZING
LIGHTS
CHILLER
AIR COMPRESSOR
FANS VENTILATION
FANS DRYER BLOWERS
PUMPS WASTE TREATMENT
PUMPS BOILER FEED, CHEMICAL FEED, ETC.
HOISTS and CONVEYORS
0%
20%
40%
60%
80%
100%

BREAKDOWN OF PROCESS HEAT ENERGY USAGE IN PLANT G



Energy Profile Plant J

Electrical Energy Usage Breakdown

Total annual Kilowatthours 1.50×10^6

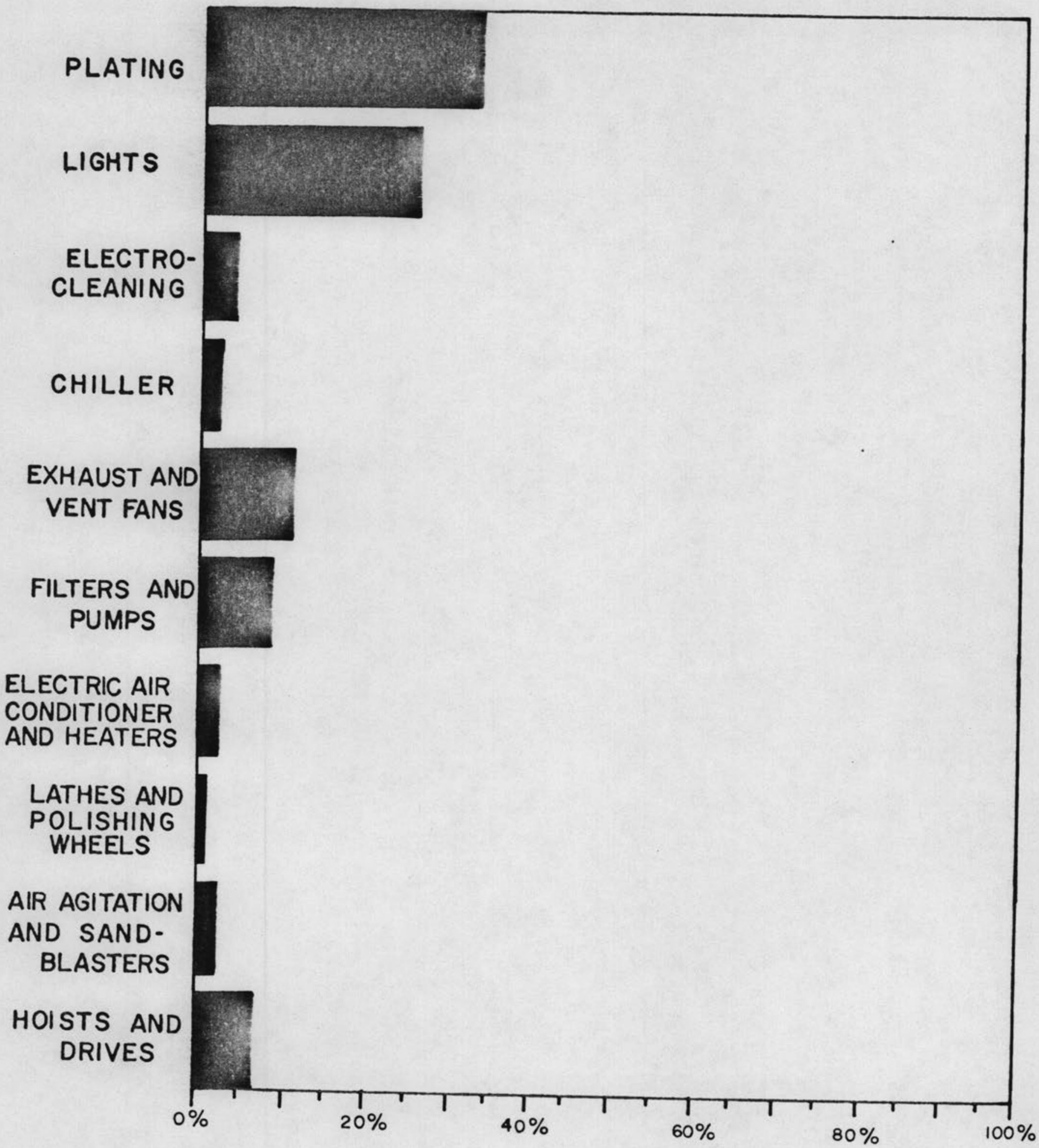
		Percent of total
1.	Plating	33.0
2.	Lights	26.0
3.	Electrocleaning	4.0
4.	Chiller	2.5
5.	Exhaust fans	11.4
6.	Filters and pumps	8.2
7.	Air conditioners and heaters	3.0
8.	Lathes and polishing wheels	1.3
9.	Air agitation blowers and sand blaster	3.0
10.	Hoists and drives	6.6
		100.0%

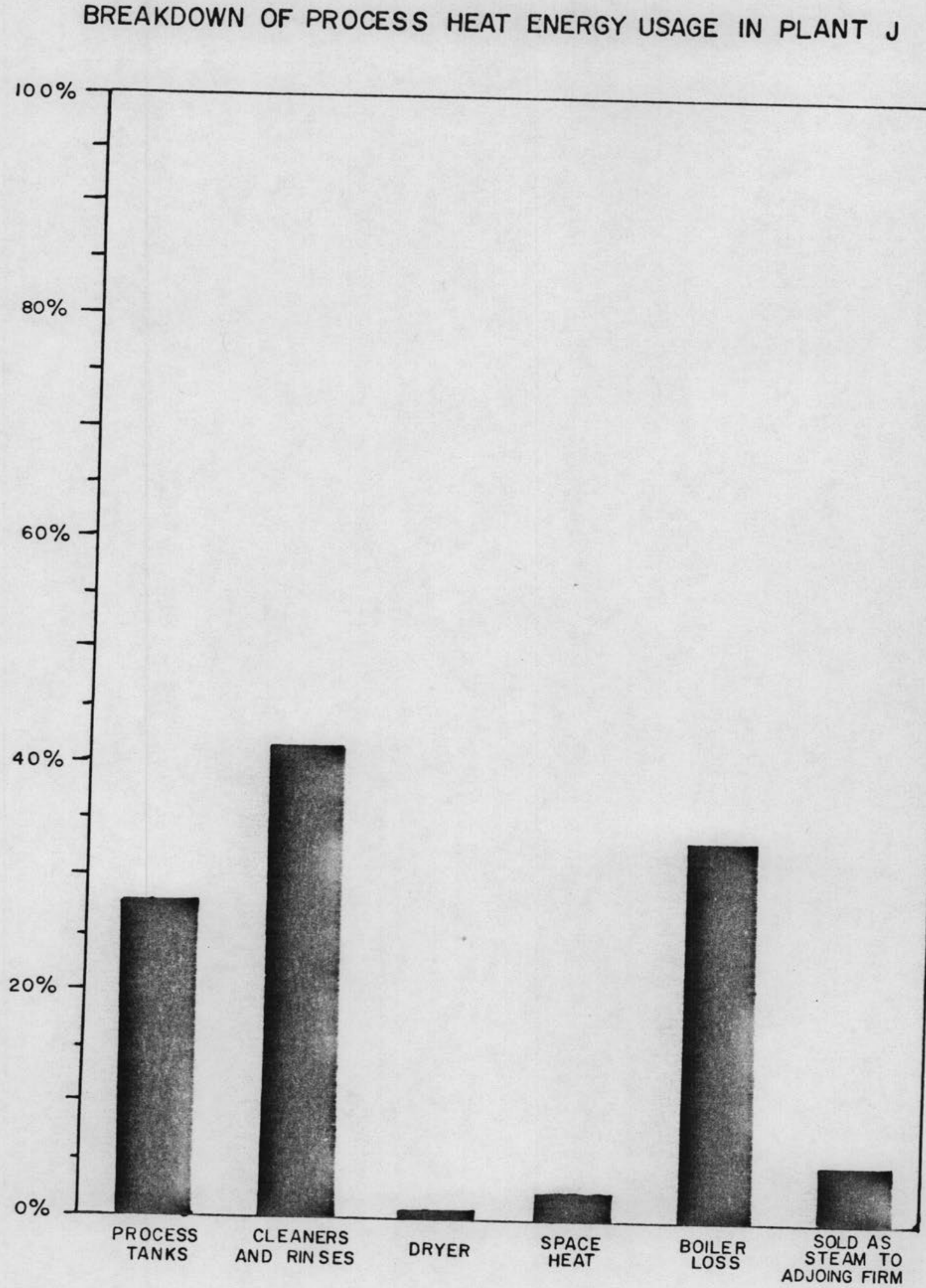
Process Heat Energy Usage Breakdown

Total annual BTU's 2.46×10^{10}

		Percent of total
1.	Process Tanks	27.7
2.	Cleaners and rinses	41.4
3.	Dryer	.9
4.	Space heat	2.1
5.	Boiler losses	23.0
6.	Sold as steam to adjacent firm	4.9
		100.0%

BREAKDOWN OF ELECTRICAL USAGE IN PLANT J




BREAKDOWN OF PROCESS HEAT ENERGY USAGE IN PLANT J
100%
80%
60%
40%
20%
0%
PROCESS TANKS
CLEANERS AND RINSES
DRYER
SPACE HEAT
BOILER LOSS
SOLD AS STEAM TO ADJOING FIRM

Energy Profile Plant 0

Electrical Energy Usage Breakdown

Total annual Kilowatthours 9.06×10^5

		Percent of total
1.	Plating	41.1
2.	Lights	8.6
3.	Electrocleaning	4.3
4.	Exhaust fans	16.0
5.	Polishing, buffing	5.0
6.	Blowers; air agitation, dryer, boiler	6.1
7.	Filters	10.3
8.	Air compressors (drive hoists)	8.2
9.	Wash pump	.4
		100.0%

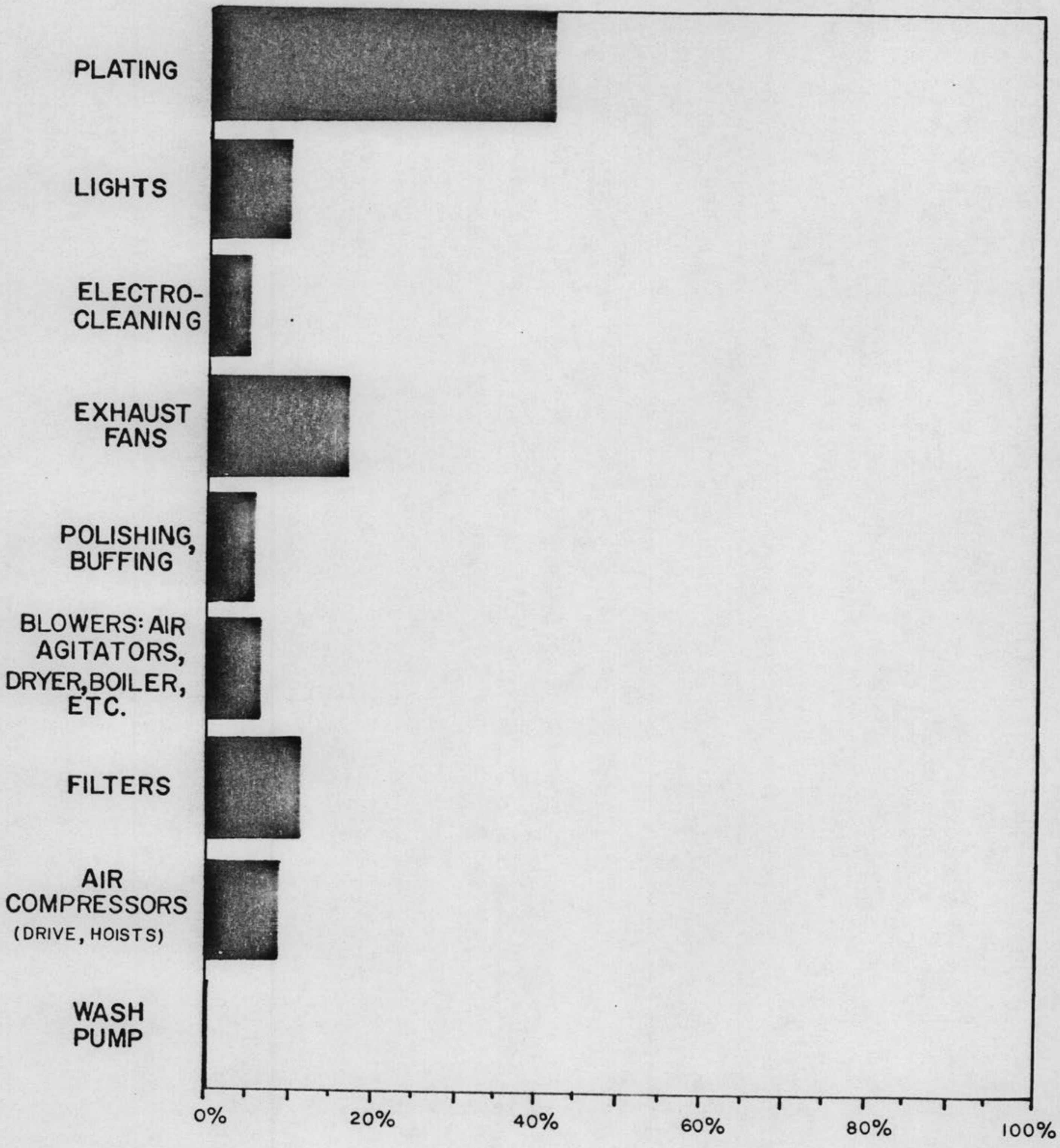
Process Heat Energy Usage Breakdown

Total annual BTU's 1.42×10^{10}

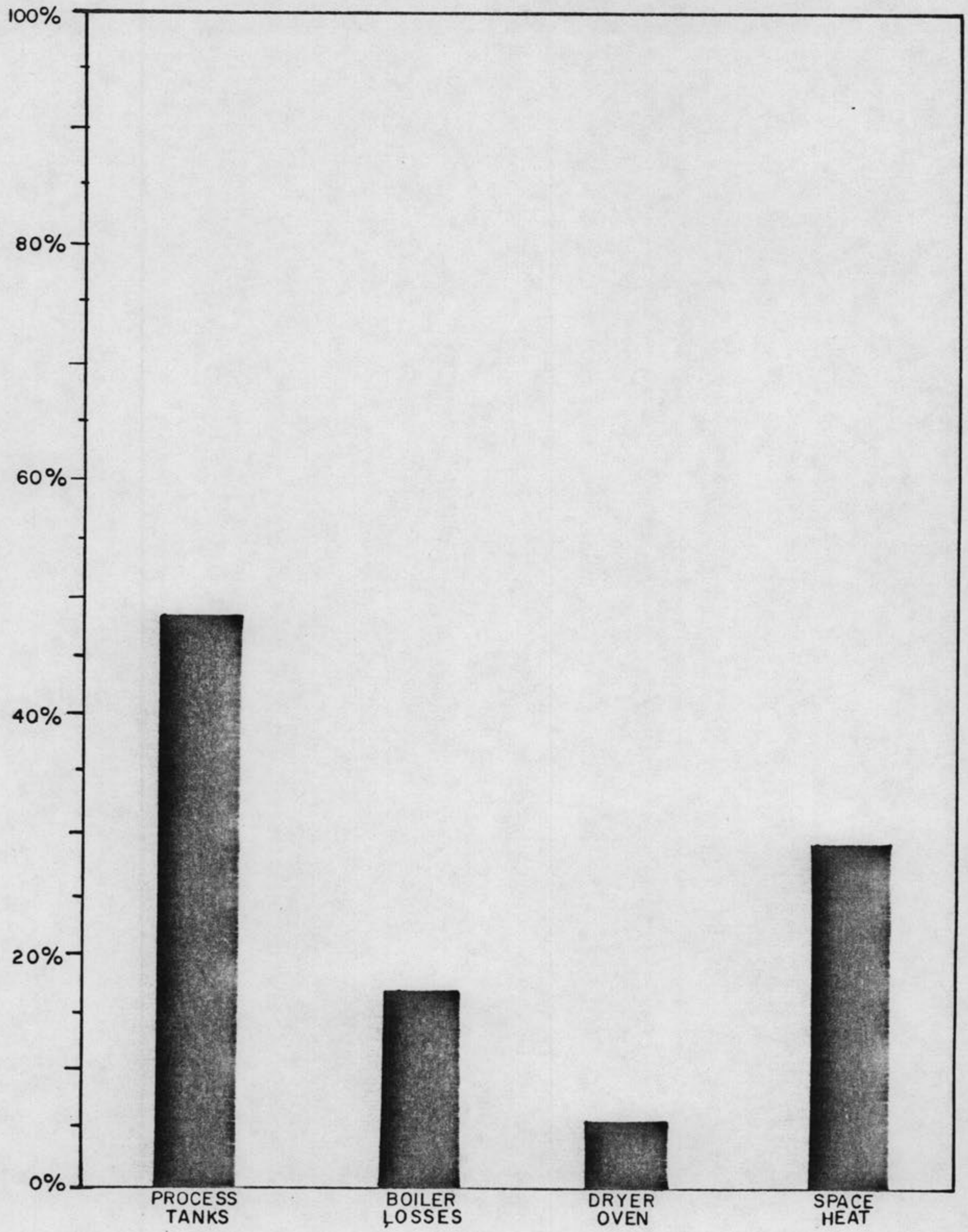
		Percent of total
1.	Process tanks	48.5
2.	Boiler losses	16.2
3.	Dryer oven	5.7
4.	Space heat	29.7
		100.0%

Note: All cleaners and rinses are ambient.

BREAKDOWN OF ELECTRICAL USAGE IN PLANT O



BREAKDOWN OF PROCESS HEAT ENERGY USAGE IN PLANT O



APPENDIX B

EXAMPLE CALCULATIONS

Electrical Usage - Plating

Apply Faraday's Law in the following form:

$$\text{grams deposited} = \frac{\text{Molecular Wt X Energy consumed (calories)}}{\text{Molar equivalent X } 23{,}060 \ \frac{\text{cal}}{\text{volt e.g.}} \text{ X voltage applied}}$$

For example zinc:

$$(36{,}000 \text{ lbs})\ 454 \text{ grams/lb} = \frac{65.4 \text{ X (calories)}}{2 \text{ x } 23{,}060 \text{ X } 7.5}$$

Where 7.5 volts is the average applied, half at 3 volts rack plating and half at 12 volts barrel plating. This is the approximate work distribution.

The calories delivered are then

$8.6 \text{ X } 10^{10}$ cals

assuming a 72 percent overall efficiency for rack plating and 40 percent for barrel plating and converting to kwhs:

$$8.6 \text{ X } 10^{10} \text{ cals } \frac{2}{(.72 + .40)\text{eff}} \text{ X } 1.16 \text{ X } 10^{-6} \text{ kwhs/cal} =$$

$1.75 \text{ X } 10^{5}$ kwhs consumed.

Lighting

A plating shop has 10,750 watts of flourescent lighting and 3500 watts of incandescent lighting operating 5 days a week 20 hours a day. The energy consumed is then

(10,750 watts)(1 kw/1000 watts)(20 hrs/da)(5 da/wk)(52 wk/yr) =

55900 kwhs/yr

add 20% to drive the lighting ballast

(55900) 1.2 = 67,100 kwh/yr.

(3500)(1 kw/1000 watts)(20 hr/da)(5 da/wk)(52 wk/yr) =

18,200 kwh/yr

The sum of the two usages gives the total plant lighting consumption as 85,300 kwhs/yr.

Electrocleaning

Energy consumption for two electrocleaning stations is calculated as follows:

#1	300 amps @ 6 volts	120 hrs/wk
#2	1000 amps @ 9 volts	60 hrs/wk

#1 (300 amp)(6v)(120 hrs/wk)(1 kw/1000 watts)(50 wk/yr) =

10,800 kwhs/yr

#2 (1000 amp)(9v)(60 hrs/wk)(1 kw/1000 watts)(50 wk/yr) =

27000 kwhs/yr

For a total of 37,800 kwhs/yr.

<u>Motors</u>

A 25 hp air compressor motor draws 50 amps on each leg of a 3 phase circuit at 220 volts. The unit runs 10 hours a day, 52 weeks a year, 5 days a week.

(220 volts)(50 amps)(1.732)(10 hrs/da)(5 da/wk)(52 wk/yr)(1 kw/1000 watts) =

(1 kw/1000 watts) = 49500 kwhs/yr

<u>Process Heat Usage - Tank Heating</u>

A plating tank is maintained at 180^oF 24 hours a day, 5 days a week. The tank dimensions are 6' long by 4' wide by 4' deep. No direct ventilation is provided. Heating is by steam at 15 psi through coils. Condensate is not returned.

Heat loss from the tank surface will be approximately:

(2100 Btu/hr ft^2)(24 ft^2)(24 hrs/da)(5 days/wk)(52 wks/yr) =

3.14×10^8 Btu/yr.

The tank walls and bottom have an average heat transfer coefficient of 2.1 Btu/hr $ft^{2o}F$, then

(2.1 Btu/hr ft^2 ^oF)(104 ft^2)(180^o - 70^oF)(24 hrs/da)(5 da/wk)(52 wk/yr) =

1.50×10^8 Btu/yr. for a total of

4.64×10^8 Btu/yr. to this we must add the heating remaining in the condensate which is not effectively used. For 15 psi steam this is about 10% of the total consumed for a grand total of

$$5.10 \times 10^8 \text{ Btu/yr.}$$

to heat this one tank.

A-2042

Quarterly Progress Report
March 1, 1977 to June 1, 1978

ENERGY CONSERVATION STUDY
OF THE
PLATING AND SURFACE FINISHING INDUSTRY

Contract No. EC 77-S-05-5487
Research Project A-2042
AES Research Project #46

Prepared for
Department of Energy
Office of Industrial Conservation
Washington, D.C.

and

American Electroplaters Society
1201 Louisiana Ave.
Winter Park, Florida

by

The Engineering Experiment Station
Georgia Institute of Technology
Atlanta, Georgia

June 1, 1978

INTRODUCTION

The Engineering Experiment Station at Georgia Tech and the American Electroplaters Society are engaged in evaluating energy consumption patterns in the electroplating industry. An engineering analysis of the energy consuming process will result in recommendations to the industry for conserving energy. Twenty electroplating shops will be surveyed, all of which have been chosen and are in some stage of developing an energy profile. Profiles have essentially been completed for fourteen plating shops and are included in this report. They are referred to by an assigned letter to maintain confidentiality.

RESEARCH ACTIVITIES

Energy Audits

Progress on the electroplating project has continued with very good response from participating plants. Energy audits for seven plants were completed in this report period. These include plants B, H, I, K, L, M, and N. Thus, energy audits have been completed for fourteen plants all of which are included in this report. The previously completed audits are of plants A, D, E, F, G, J and O. The basic purpose of an energy audit is to:

1. Identify energy consuming operations.
2. Define the amount and mechanisms of energy usage.

This is done for both electrical energy usage and process heat energy usage in each plant. The results are presented in appendix A for each shop individually. This information will help point out the areas of greatest potential savings.

Discussion of Results

Two patterns of energy usage have emerged, with one pattern appearing to be far more prevalent. Plants in this pattern group plate zinc, copper, nickel and chrome, among other metals, in large quantities for decorative purposes and corrosion protection. Plating consumes from 10% to 55% of their electrical energy. Some anodizing is also done in two of these plants while one facility is devoted strictly to anodizing. This plant is included in the first pattern group. (See tables 1 and 2.) Only plants A and K are not included in this group. They are best described in a separate category.

The second pattern of energy usage is typified by the plating of electronic parts that are small in size. Plating consumes around 2% of the electrical energy consumed. Plating tanks are smaller and are heated electrically, whereas the first pattern shops predominately heat via steam. Two plants of this type have been surveyed, plants A and K.

The average ratio of process heat energy to electrical energy consumed in plants which plate only (no anodizing or paint work performed) is

5.3 to 1. This includes plant A which is unique because all process heating is done electrically. The same ratio is 9.2 to 1 for all plants surveyed to date. This ratio indicates that the greatest potential savings are to be found in the area of heat generation and use, with natural gas being the most common source of plant and process heat. These ratios are for energy delivered to the plant boundary. If an overall efficiency for electrical generation and transmission of about 28% is considered then the ratio of process heat energy to electrical energy consumed is on the order of 2.6 to 1.

TABLE 1

Average Electrical Energy Consumption

First Pattern Group

1.	Plating (and/or anodizing)	31.3
2.	Lights	13.4
3.	Electrocleaning	3.2
	Motors (as below)	
4.	Exhaust fans	20.8
5.	Blowers; dryer, oven, air agitation etc. boiler etc.	4.9
6.	Pumps (all)	7.9
7.	Hoists and drives	5.7
8.	Chillers	3.9
9.	Other	8.9
		100.0%

TABLE 2

Average Electrical Energy Consumption

First Pattern Group

1.	Dryers and ovens	11.1
2.	Space heat	8.8
3.	Process tanks (including anodizing)	32.0
4.	Rinses and cleaners	20.5
5.	Boiler losses	19.3
6.	Vapor degreasers	4.9
7.	Other	3.4
		100.0%

RECOMMENDED MODIFICATIONS

The plating industry, as represented by the plants surveyed thus far, has several areas of opportunity to conserve energy. These include but are not limited to the following:

Condensate Return - Some platers return some condensate but many return none at all. Roughly half of the plants surveyed return condensate from certain "safe" areas. No plating plant returned condensate from a chrome or sulfuric acid bath. For a plating plant that does not return any condensate, the potential savings are on the order of 11-12% of the fuel consumed in the boiler room.

Use of Infrared in Space Heating - Plants with a large proportion (greater than 20%) of their process heat energy consumed in space heating universally utilize direct fired air make-up units. These plants can benefit from the use of infrared heaters which radiate heat to objects and people rather than preheat the enormous amounts of incoming air. A reduction of 30 to 35% in plant heating bills can be expected.

Reuse of Waste Heat - Several opportunities exist to reuse waste heat. Compressor and vapor degreaser cooling water can be reused in rinsing or as boiler make-up. Cascade rinses allow for more efficient use of process heat. Dryer, oven and boiler exhausts offer the possibility of heat recovery.

Use of the Oscilloscope and Replacement of Inefficient Rectifiers and Motor Generator Sets - Two participating plants which are operating aged rectifiers and motor generator sets have estimated the efficiencies of these units using an oscilloscope. Some units which physically did not appear to be in poor condition, nonetheless, exhibited efficiencies as low as 30 to 40%! This has allowed the company to replace the worst units first as capital money becomes available. It also points out the capabilities of the oscilloscope as a diagnostic tool. Rectifiers can suffer an efficiency loss for many reasons, such as scaling of the cooling coils. Diagnostic tools can help minimize the associated losses.

Covers on Heated Tanks - Evaporation is the largest source of heat loss from a hot plating tank. A cover of some sort can help reduce losses substantially. Plastic ball blankets, although not well suited to all applications, are claimed to reduce evaporation losses by as much as 70%. A few platers have installed hinged covers on hand line tanks where actual throughput is low but heating is continuous. Completely enclosing a plating line, thus reducing both heat energy loss and ventilation requirements, is a concept with significant energy savings potential.

Oversized Equipment - Often, requirements in a plant will change, such as for compressed air. Two of the plants visited had lowered their need for compressed air but continued to operate their now oversized compressor. In one case 73% of the electricity consumed was used while idling. Although immediate replacement of the unit may not be economically attractive, the need for major repair on the unit should initiate a replacement of the proper size.

Turndown, Turnoff - Almost all of the plants visited to date have had some piece of equipment running that simply was not being used at the time. Whether an empty tumbler, conveyor, dryer or unnecessary lights, most equipment simply needed someone to turn it off. Often the task can be automated with an on-off solenoid valve and a sensing device to determine whether or not material is entering the equipment.

Plating baths and other heated tanks can often be lowered in temperature without affecting plating performance. Indeed many tanks were found to be at a temperature higher than specified by the company operator's manual. Lowering a bath temperature even a few degrees can result in a significant saving.

These are just a few of the ideas which are growing out of this project. Many will be covered in greater detail in the project final report along with others that can be of benefit to the plating industry.

Appendix A, which follows, contains energy profiles for the fourteen facilities surveyed thus far. Appendix B contains example calculations.

The article, "Getting Energy Conservation off the Ground Floor", included in the first quarterly report is now scheduled to be published in the AES journal "Plating and Surface Finishing".

APPENDIX A
PLANT ENERGY PROFILES

Plant A Energy Profile

Note: Plant A is unique for two reasons:

1) The work plated is small in size compared to other shops.

2) All process heating is done electrically, natural gas is used only for building heat in winter months, and for domestic purposes.

Electrical Energy Usage Breakdown

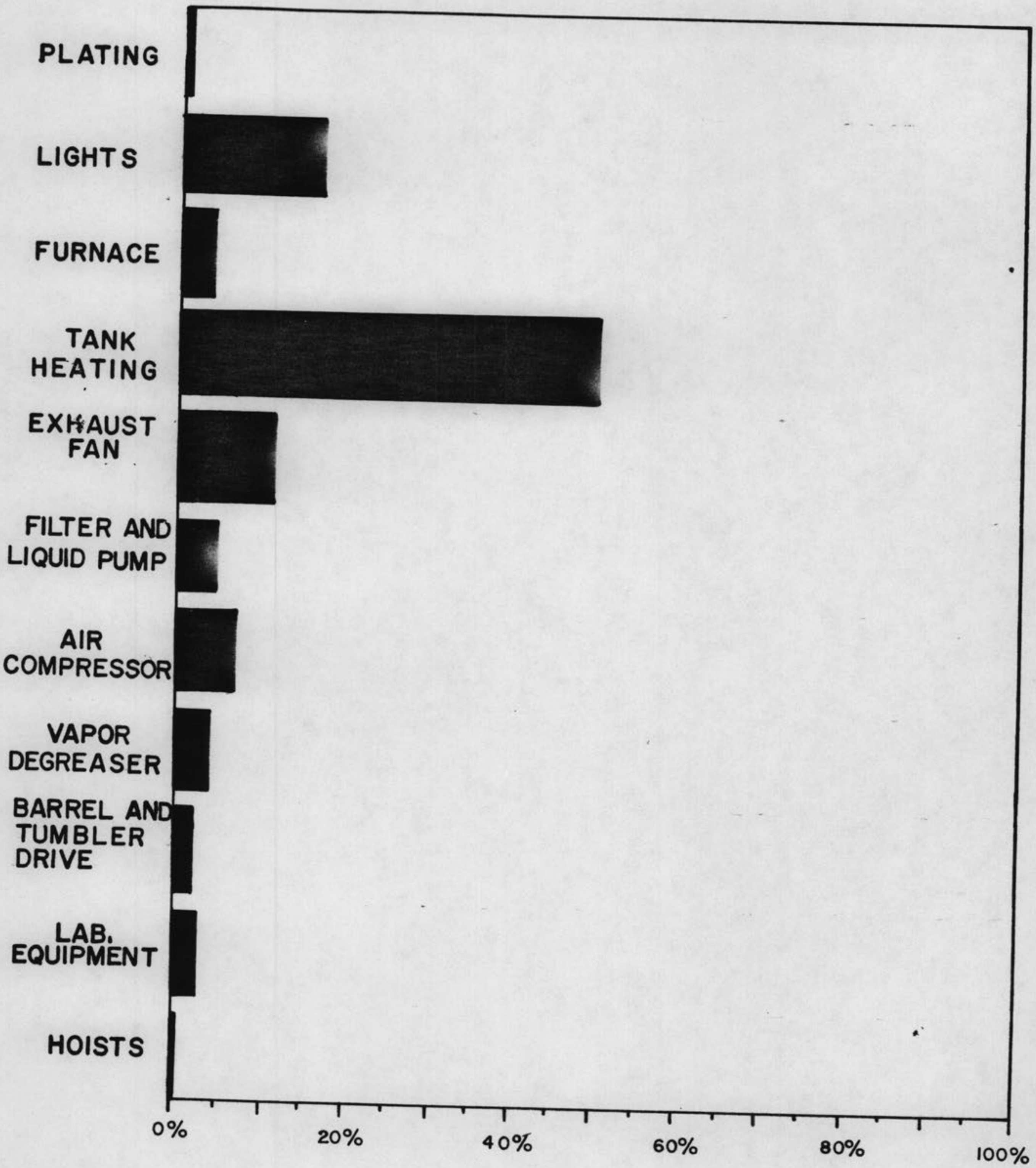
Total annual kilowatt-hours 1.18×10^6

		Percent of total
1.	Plating	.9
2.	Lights	16.3
3.	Cracking Furnace	3.4
4.	Tank Heat	50.0
5.	Exhaust Fans	10.4
6.	Filter and liquid pumps	3.7
7.	Air compressors	5.8
8.	Vapor Degreasers	3.5
9.	Barrel and Tumbler drives	2.4
10.	Lab Equipment	2.9
11.	Hoists	.7
		100.0%

Process Heat Energy Usage Breakdown

Total natural gas usage 1977 approximately 59000 therms, 98.4 percent of which was consumed in plant heating. The remaining 1.6 percent was consumed in heating water for domestic use.

BREAKDOWN OF ELECTRICAL USAGE IN PLANT A



Plant B Energy Profile

Electrical Energy Usage Breakdown

Total annual kilowatt-hours 2.92×10^6

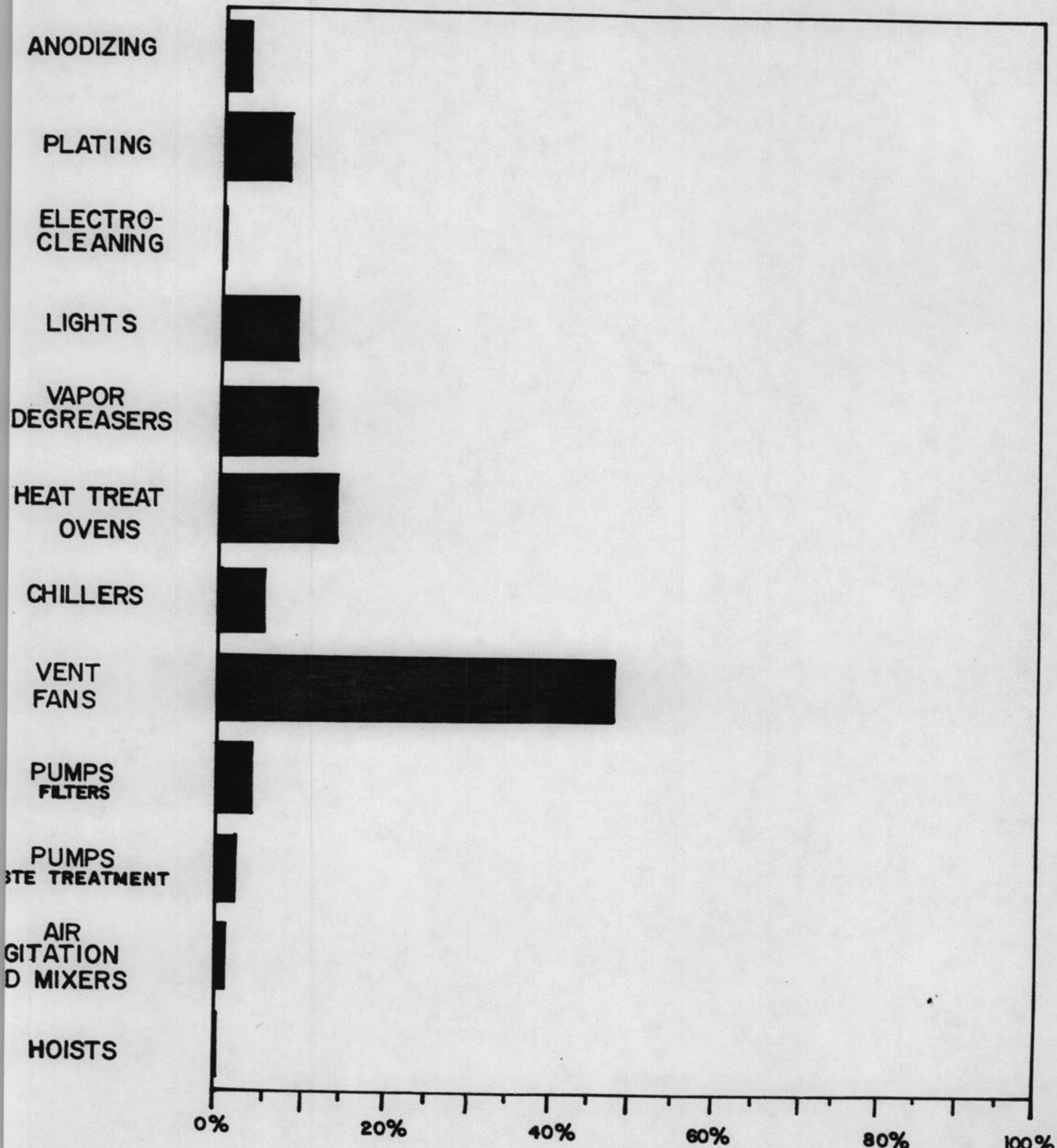
		Percent of total
1.	Anodizing	2.1
2.	Plating	7.1
3.	Electrocleaning	.2
4.	Lights	8.5
5.	Vapor degreasers (all electric)	11.1
6.	Heat treat ovens	13.8
7.	Chillers	4.7
8.	Vent fans	47.2
9.	Pumps: filters	3.2
10.	waste treatment	1.3
11.	Air agitation and mixers	.7
12.	Hoists	.1
		100.0%

Process Heat Energy Usage Breakdown

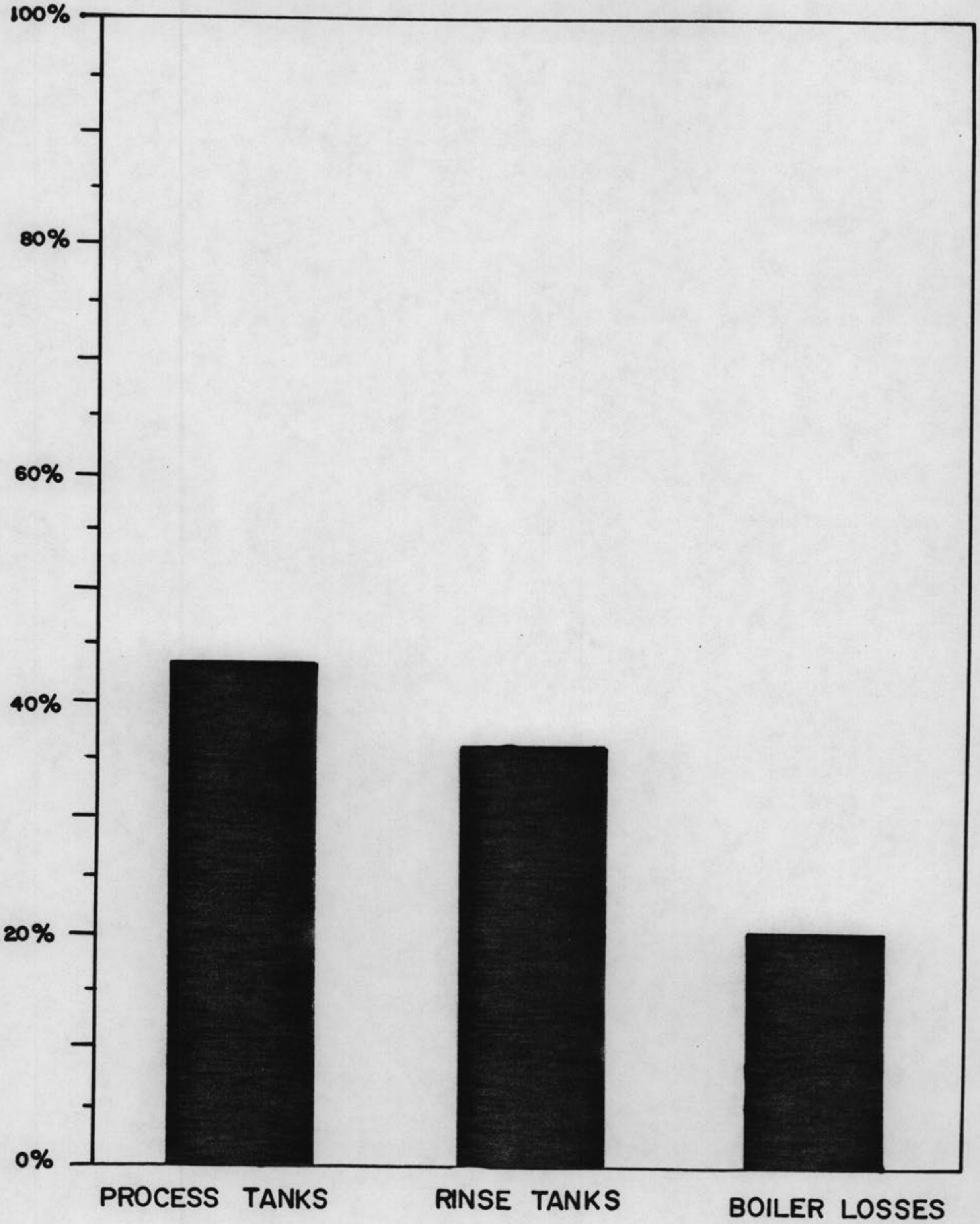
Total annual BTU's 9.01×10^{10}

		Percent of total
1.	Process tanks	43.5
2.	Rinse tanks	36.5
3.	Boiler losses	20.0
		100.0%

BREAKDOWN OF ELECTRICAL ENERGY USAGE IN PLANT B



BREAKDOWN OF PROCESS HEAT ENERGY USAGE IN PLANT B



Plant D Energy Profile

Electrical Energy Usage Breakdown

Total annual kilowatt-hours 4.95×10^6

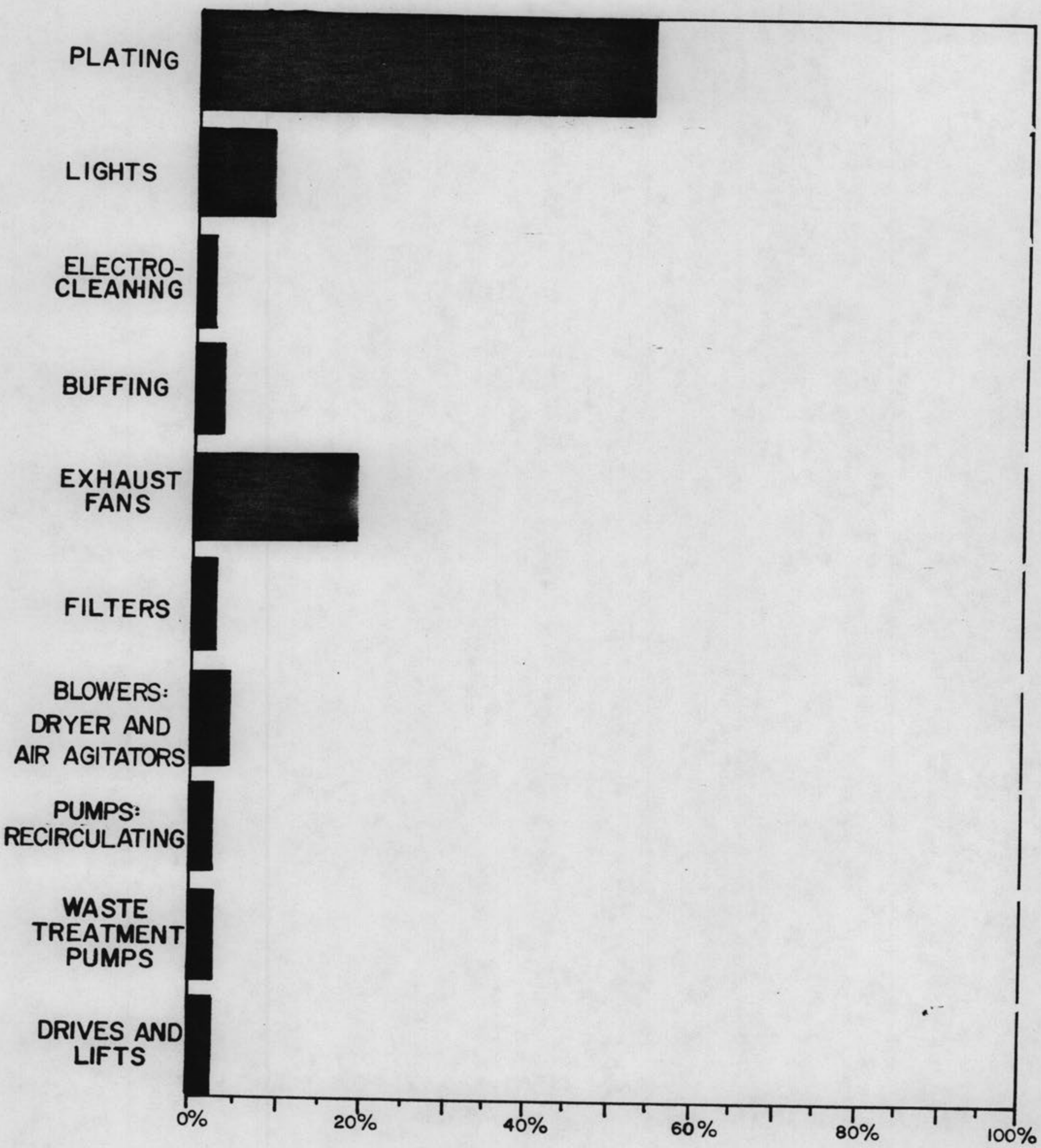
		Percent of total
1.	Plating	54.1
2.	Lights	8.5
3.	Electrocleaning	1.8
4.	Buffing	3.0
5.	Exhaust fans	19.1
6.	Filters	2.3
7.	Blowers: Dryers, Air agitation, boiler	4.4
8.	Pumps recirculating	2.2
9.	Waste treatment pumps	2.4
10.	Drives and Lifts	2.2
		100.0%

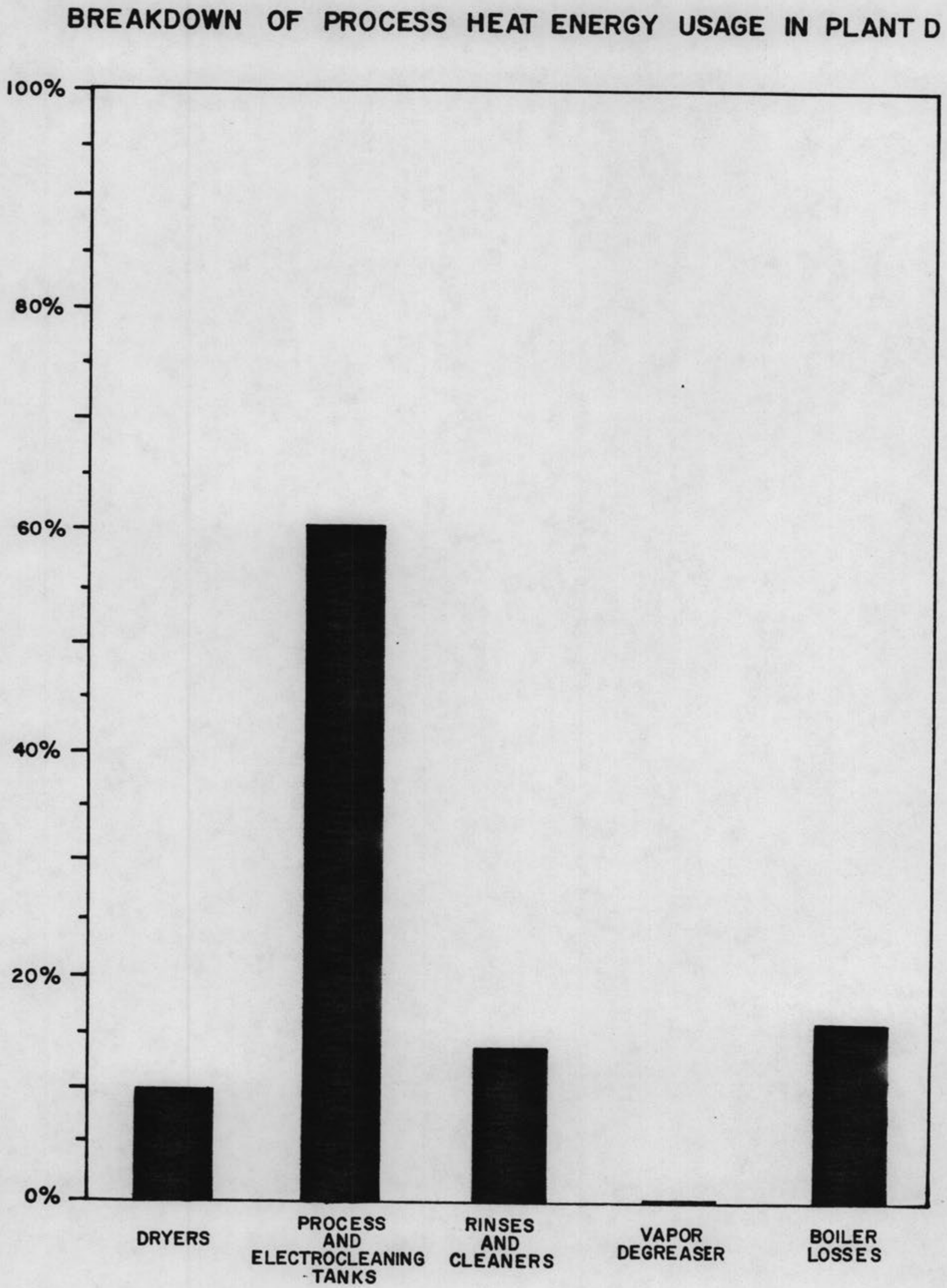
Process Heat Energy Usage Breakdown

Total annual BTU's 1.49×10^{11}

		Percent of total
1.	Dryers	9.9
2.	Process and electrocleaning tanks	60.4
3.	Rinses and cleaners	13.2
4.	Vapor degreasers	.3
5.	Boiler losses	16.2
		100.0%

BREAKDOWN OF ELECTRICAL USAGE IN PLANT D




BREAKDOWN OF PROCESS HEAT ENERGY USAGE IN PLANT D
100%
80%
60%
40%
20%
0%
DRYERS
PROCESS AND ELECTROCLEANING TANKS
RINSES AND CLEANERS
VAPOR DEGREASER
BOILER LOSSES

Plant E Energy Profile

Electrical Energy Usage Breakdown

Total annual kilowatt-hours 5.75×10^5

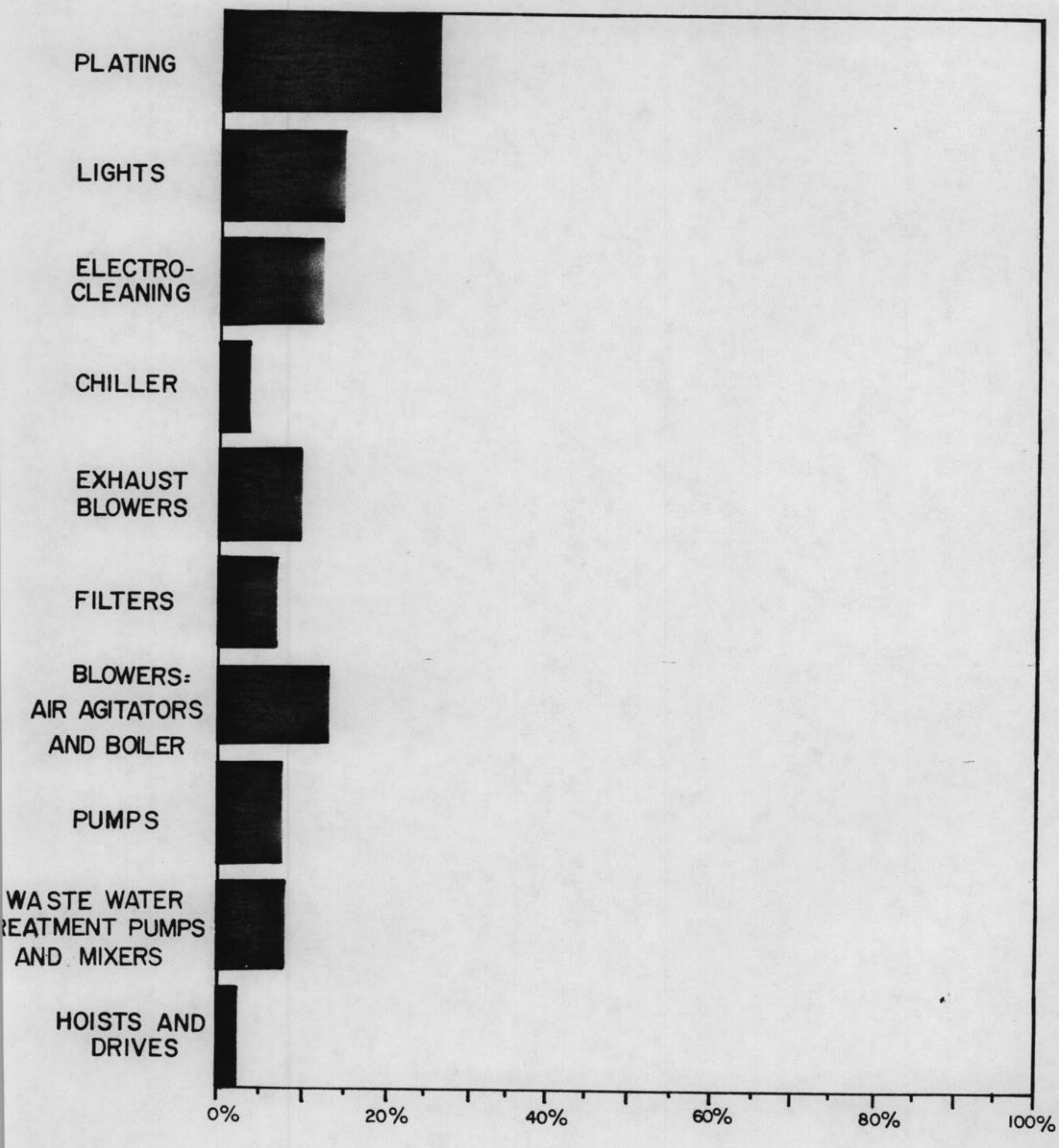
	Percent of total
1. Plating	25.7
2. Lights	14.3
3. Electrocleaning	11.3
4. Chiller	3.2
5. Exhaust fans	9.8
6. Filters	6.1
7. Blowers; air agitation and boilers	13.5
8. Pumps	6.8
9. Waste treatment pumps and mixers	7.0
10. Hoists and drives	2.4
	100.0%

Process Heat Energy Usage Breakdown

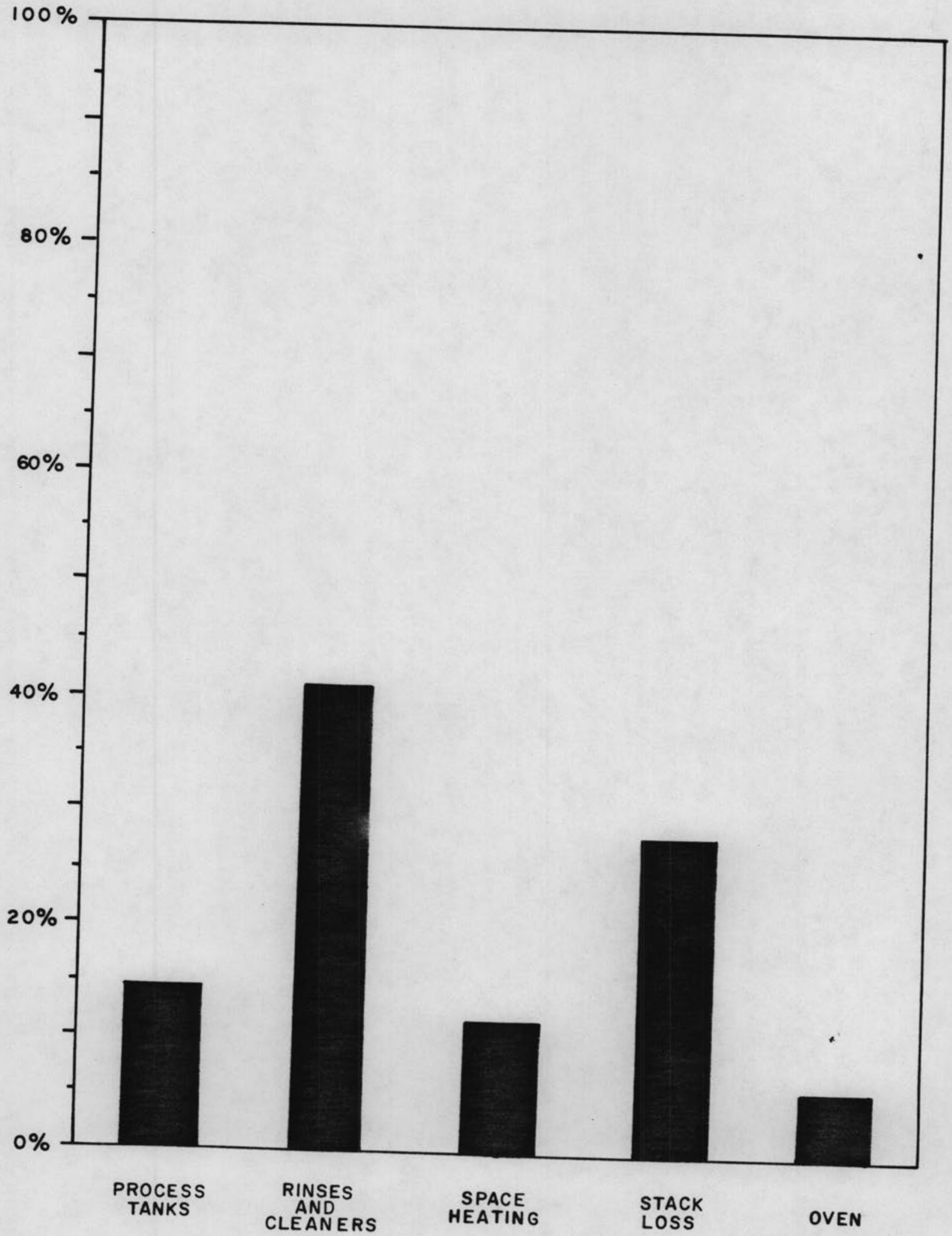
Total annual BTU's 1.05×10^{10}

	Percent of total
1. Process tanks	14.3
2. Rinses and cleaners	41.0
3. Space heating	11.4
4. Stack loss	27.6
5. Oven	5.7
	100.0%

BREAKDOWN OF ELECTRICAL USAGE IN PLANT E



BREAKDOWN OF PROCESS HEAT ENERGY USAGE IN PLANT E



Energy Profile Plant F

Electrical Energy Usage Breakdown

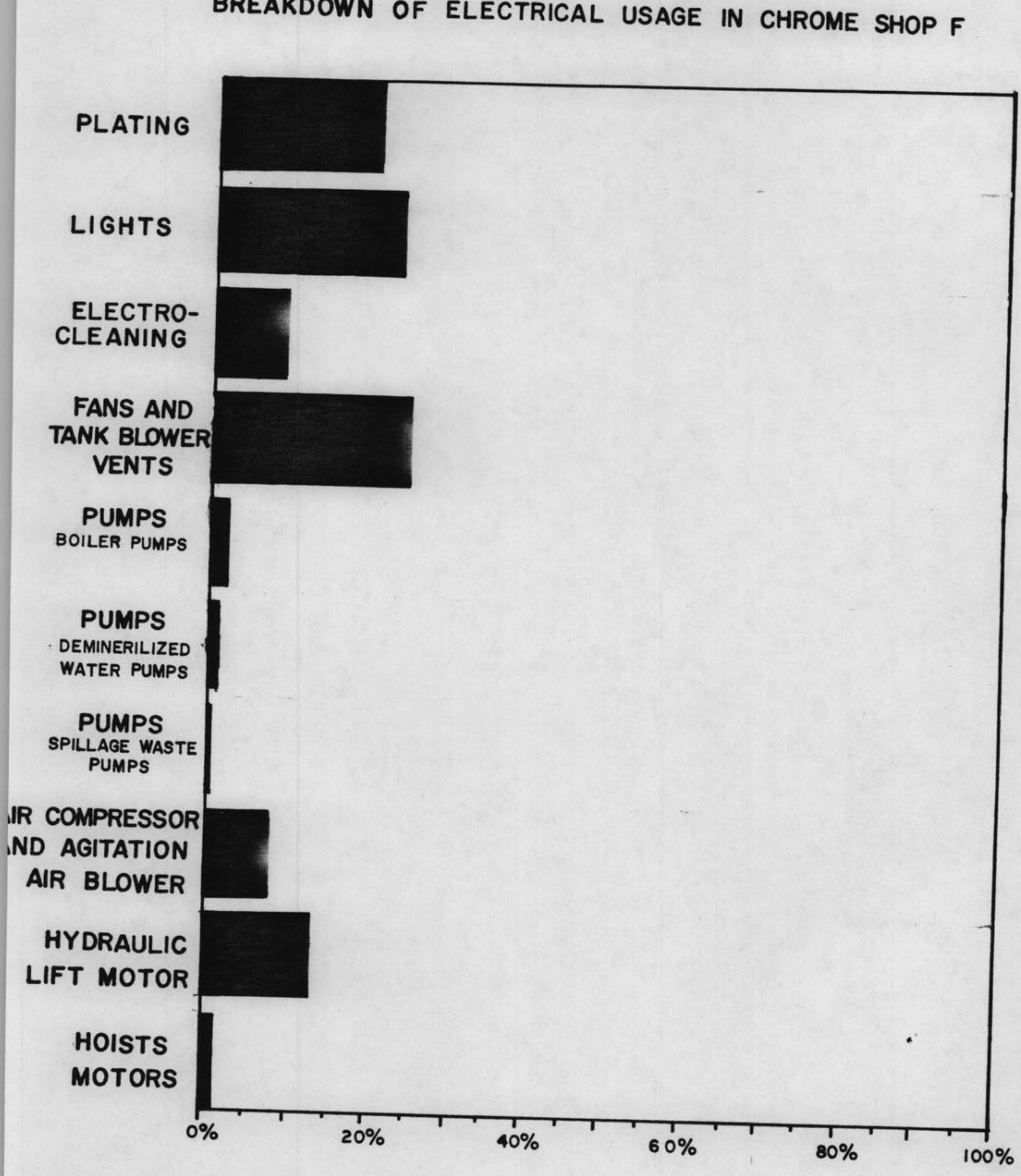
Total annual kilowatt-hours 3.03×10^5

		Percent of total
1.	Plating	20.0
2.	Lights	23.0
3.	Electrocleaning	8.0
4.	Exhaust Fans	24.7
5.	Boiler pumps	2.0
6.	Demineralized water pumps	1.0
7.	Spillage waste pumps	.2
8.	Air compressor and agitator blowers	7.4
9.	Hydraulic lift motor	12.4
10.	Hoist motors	1.3
		100.0%

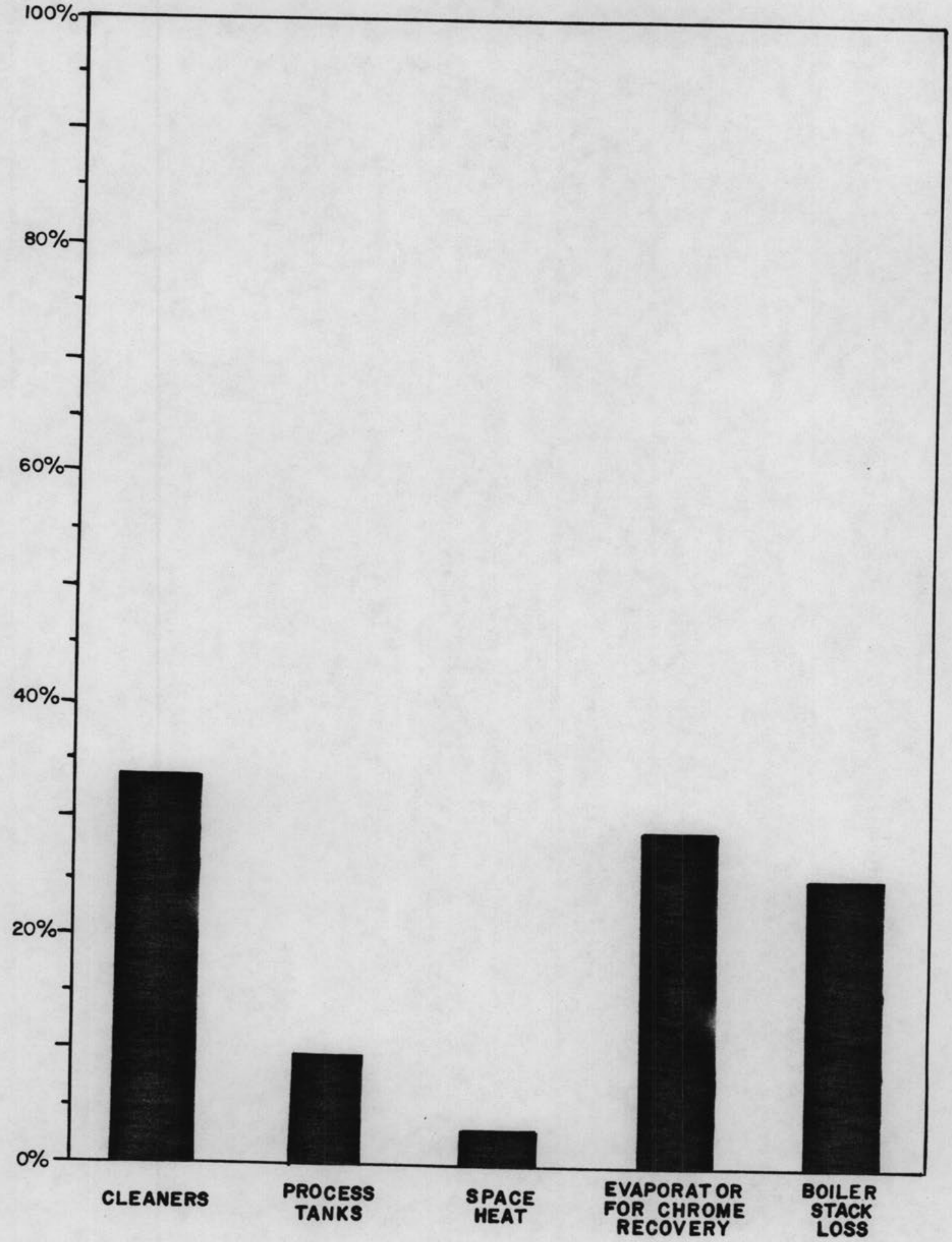
Process Heat Energy Usage Breakdown

Total annual Btu's 1.51×10^{10}

		Percent of total
1.	Cleaners	33.7
2.	Process tanks	9.6
3.	Space heat	2.7
4.	Evaporator for chrome recovery	28.9
5.	Boiler stack loss	25.1
		100.0%


BREAKDOWN OF ELECTRICAL USAGE IN CHROME SHOP F
PLATING
LIGHTS
ELECTRO-CLEANING
FANS AND TANK BLOWER VENTS
PUMPS
BOILER PUMPS
PUMPS
DEMINERILIZED WATER PUMPS
PUMPS
SPILLAGE WASTE PUMPS
IR COMPRESSOR ND AGITATION AIR BLOWER
HYDRAULIC LIFT MOTOR
HOISTS MOTORS
0%
20%
40%
60%
80%
100%

BREAKDOWN OF PROCESS HEAT ENERGY USAGE IN PLANT F



Energy Profile Plant G

Electrical Energy Usage Breakdown

Total annual kilowatt-hours 4.45×10^6

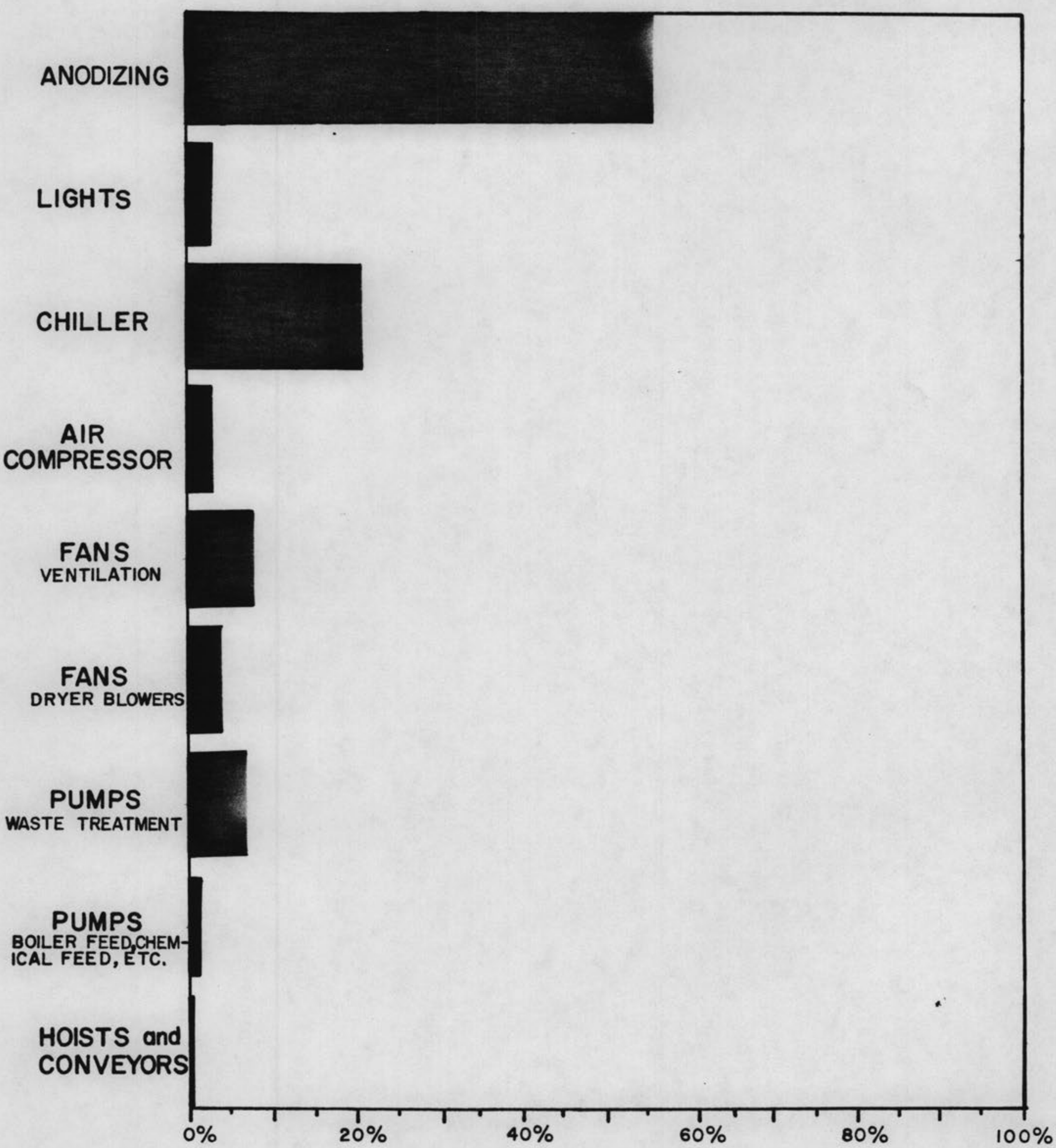
	Percent of total
1. Anodizing	55.0
2. Lights	2.0
3. Chiller	20.0
4. Air compressor	2.5
5. Exhaust fans	8.0
6. Dryer Blowers	4.0
7. Waste treatment pumps	7.0
8. Boiler feed, chemical feed pumps	1.0
9. Hoists and conveyors	.5
	100.0%

Process Heat Energy Usage Breakdown

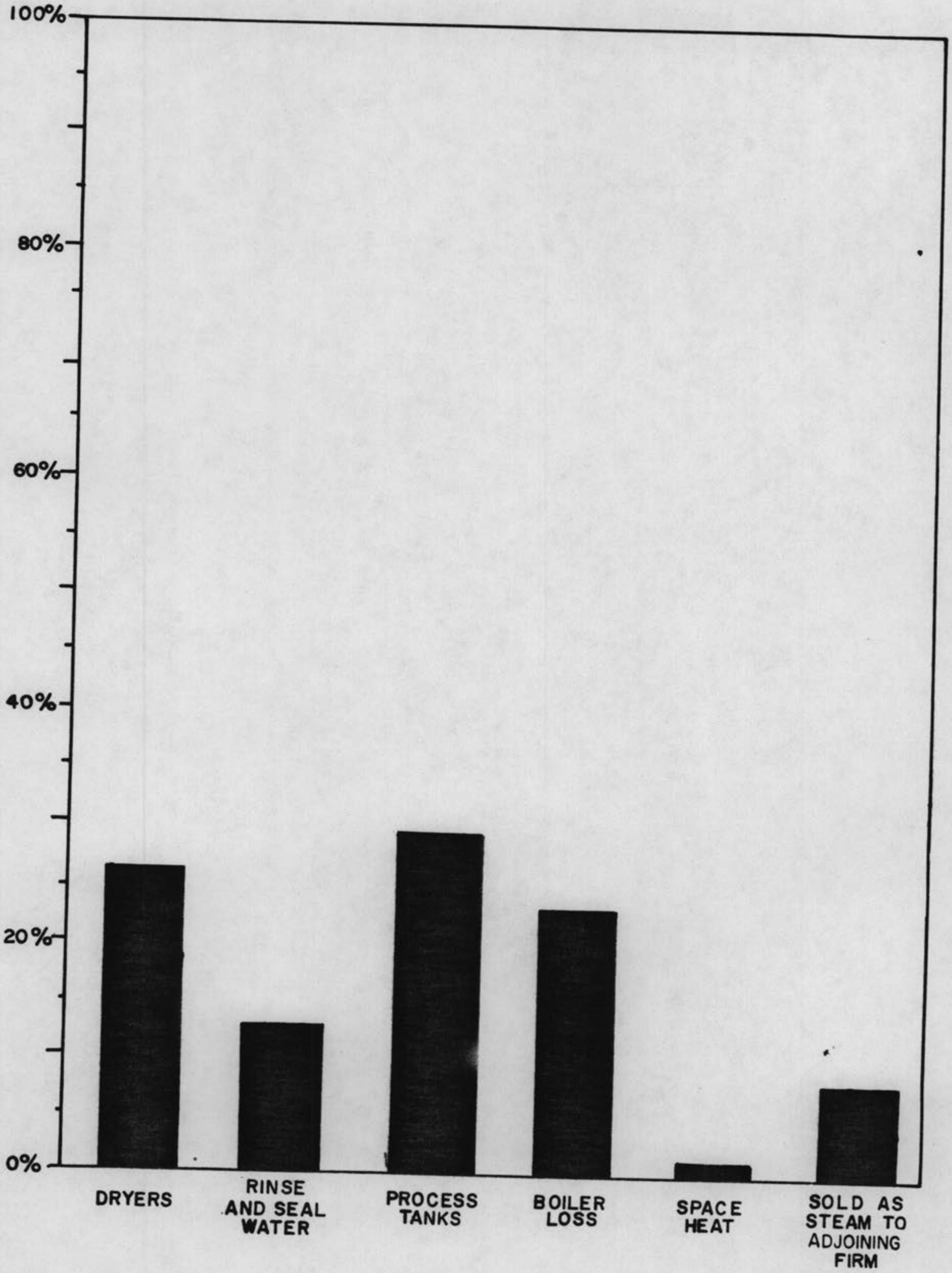
Total annual BTU's 6.53×10^{10}

	Percent of total
1. Dryers	
a. Gas	7.2
b. Steam	19.1
2. Tank heating	42.0 (as below)
a. Rinses	1.5
b. Cleaners	1.5
c. Brightners	25.7
d. Acetate	2.3
e. Seal water	11.0
	42.0%
3. Boiler loss	23.2
4. Space heat	1.0
5. Sold as steam to adjoining firm	7.5
	100.0%

BREAKDOWN OF ELECTRICAL USAGE IN ANODIZING SHOP G



BREAKDOWN OF PROCESS HEAT ENERGY USAGE IN PLANT G



Plant H Energy Profile

Electrical Energy Usage Breakdown

Total annual kilowatt-hours 9.92×10^5

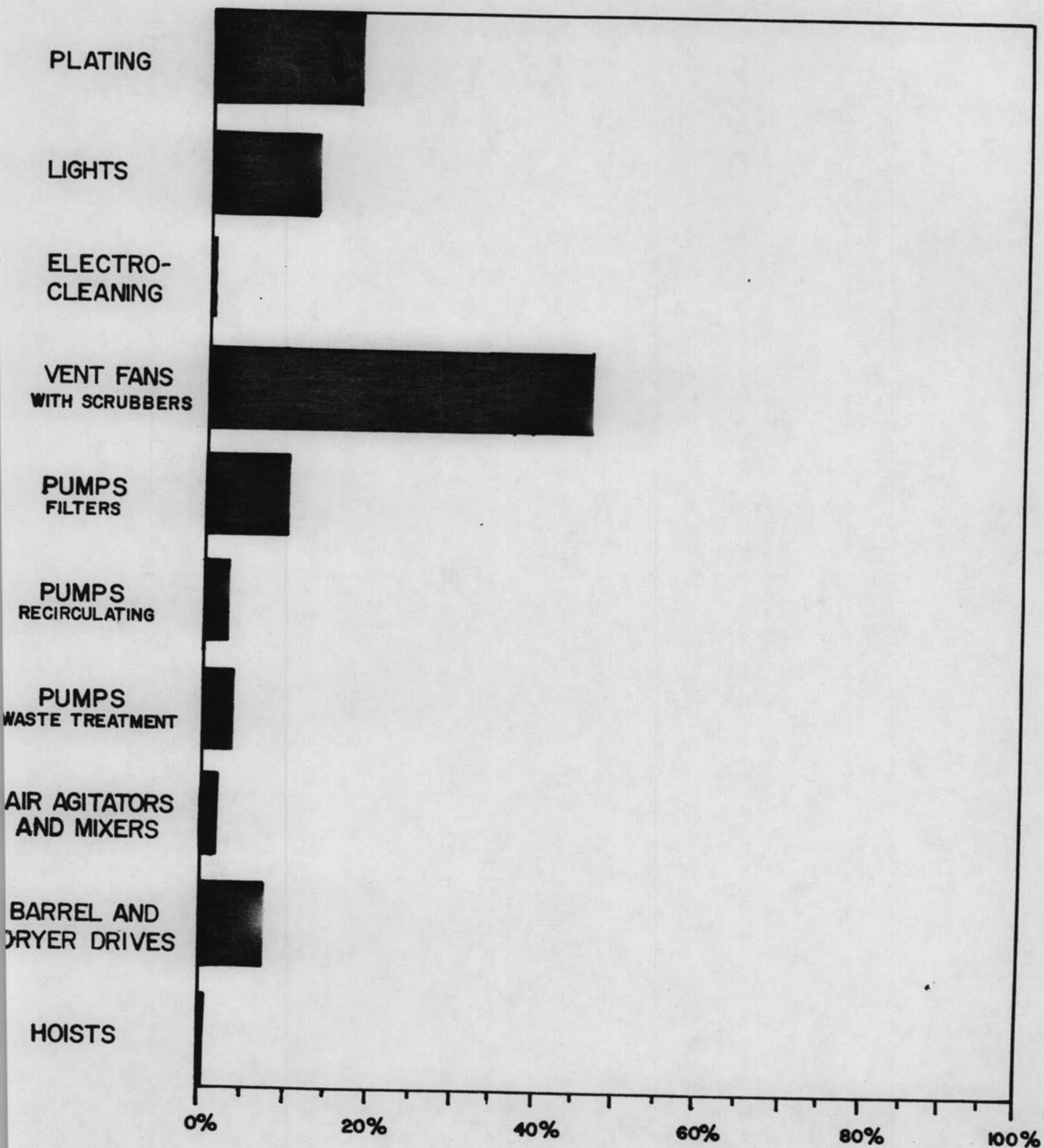
		Percent of total
1.	Plating	17.5
2.	Lights	11.9
3.	Electrocleaning	.2
4.	Vent fans (with scrubbers)	46.8
5.	Pumps; filters	9.0
6.	recirculating	2.5
7.	waste treatment	3.1
8.	Air agitation and mixers	2.0
9.	Barrel and dryer drivers	6.8
10.	Hoists	.2
		100.0%

Process Heat Energy Usage Breakdown

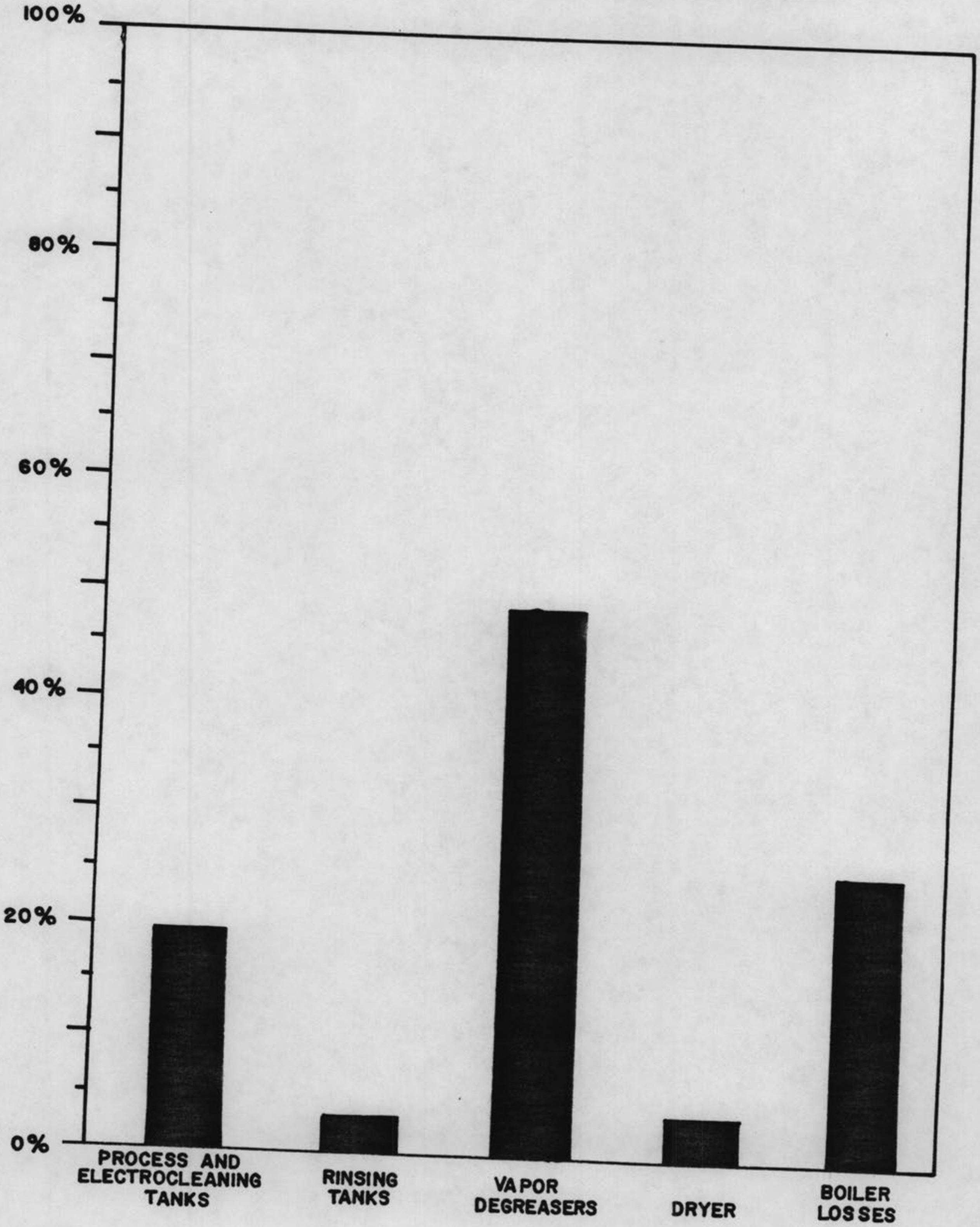
Total annual BTU's 1.33×10^{10}

		Percent of total
1.	Process and electrocleaning tanks	19.8
2.	Rinsing tanks	2.9
3.	Vapor degreasers	48.6
4.	Dryer	3.5
5.	Boiler losses	25.2
		100.0%

BREAKDOWN OF ELECTRICAL USAGE IN PLANT H



BREAKDOWN OF PROCESS HEAT ENERGY USAGE IN PLANT H



Plant I Energy Profile

Electrical Energy Usage Breakdown

Total annual kilowatt-hours 1.22×10^6

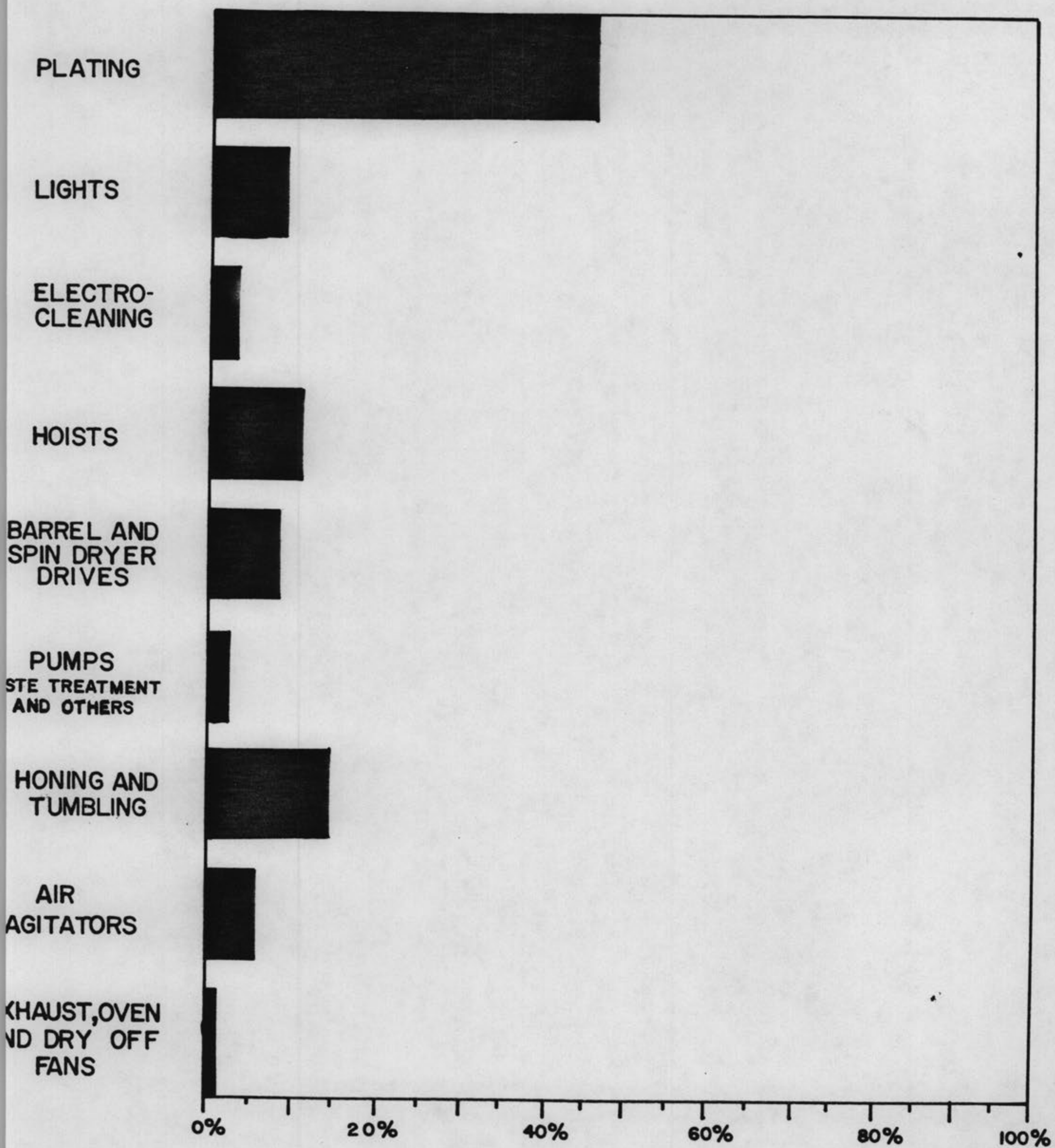
		Percent of total
1.	Plating	46.0
2.	Lights	8.3
3.	Electrocleaning	3.4
4.	Hoists	10.1
5.	Barrel and spin dryer drives	8.2
6.	Pumps waste treatment and others	2.2
7.	Honing and tumbling	14.6
8.	Air agitation	6.0
9.	Exhaust, oven and dry off fans	1.2
		100.0%

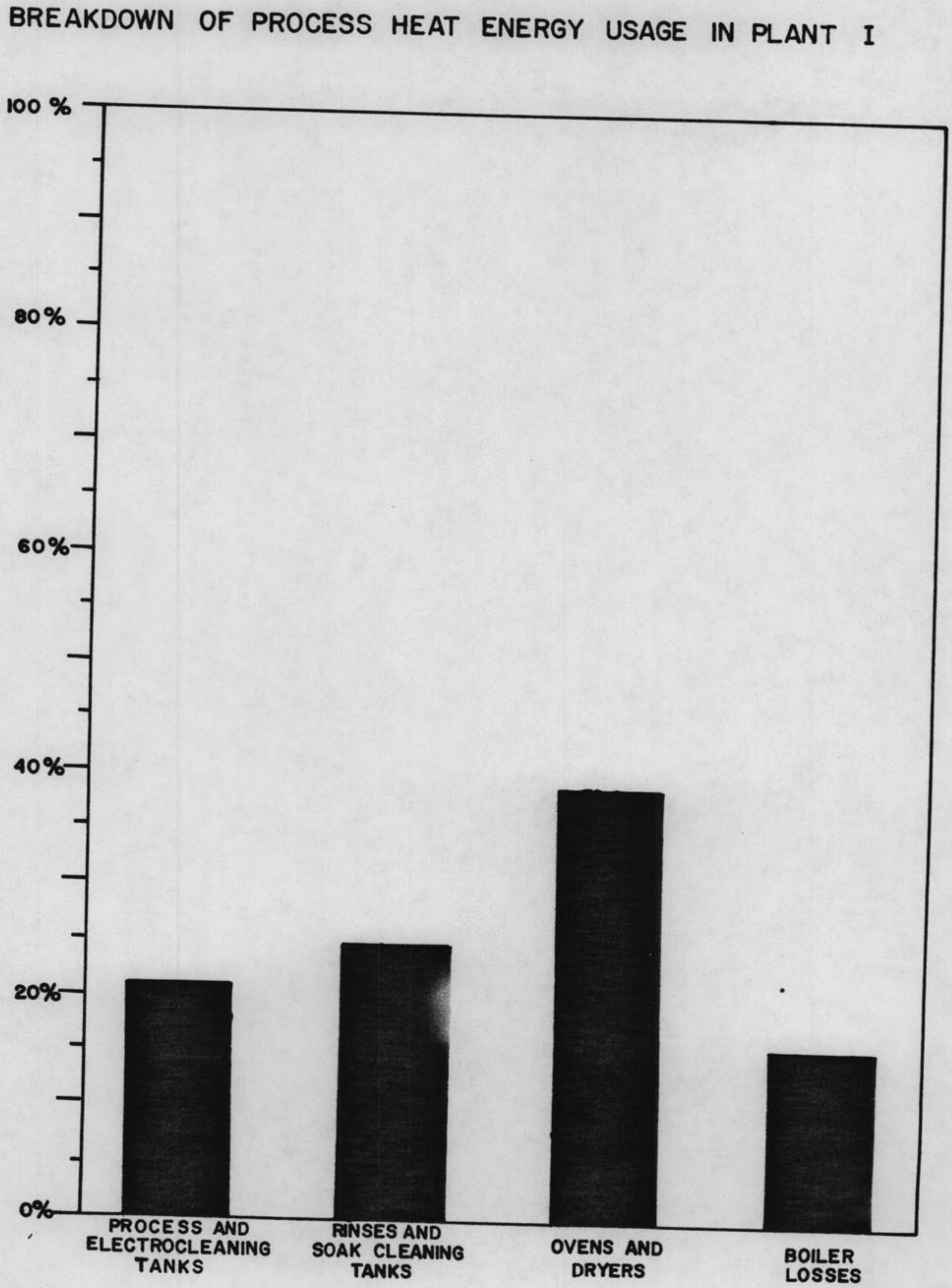
Process Heat Energy Usage Breakdown

Total annual BTU's 1.03×10^{10}

		Percent of total
1.	Process and electrocleaning tanks	21.6
2.	Rinses and soak cleaner tanks	24.7
3.	Ovens and dryers	38.3
4.	Boiler losses	15.4
		100.0%

BREAKDOWN OF ELECTRICAL USAGE IN PLANT I




BREAKDOWN OF PROCESS HEAT ENERGY USAGE IN PLANT I
100 %
80 %
60 %
40 %
20 %
0 %
PROCESS AND ELECTROCLEANING TANKS
RINSES AND SOAK CLEANING TANKS
OVENS AND DRYERS
BOILER LOSSES

Energy Profile Plant J

Electrical Energy Usage Breakdown

Total annual kilowatt-hours 1.50×10^6

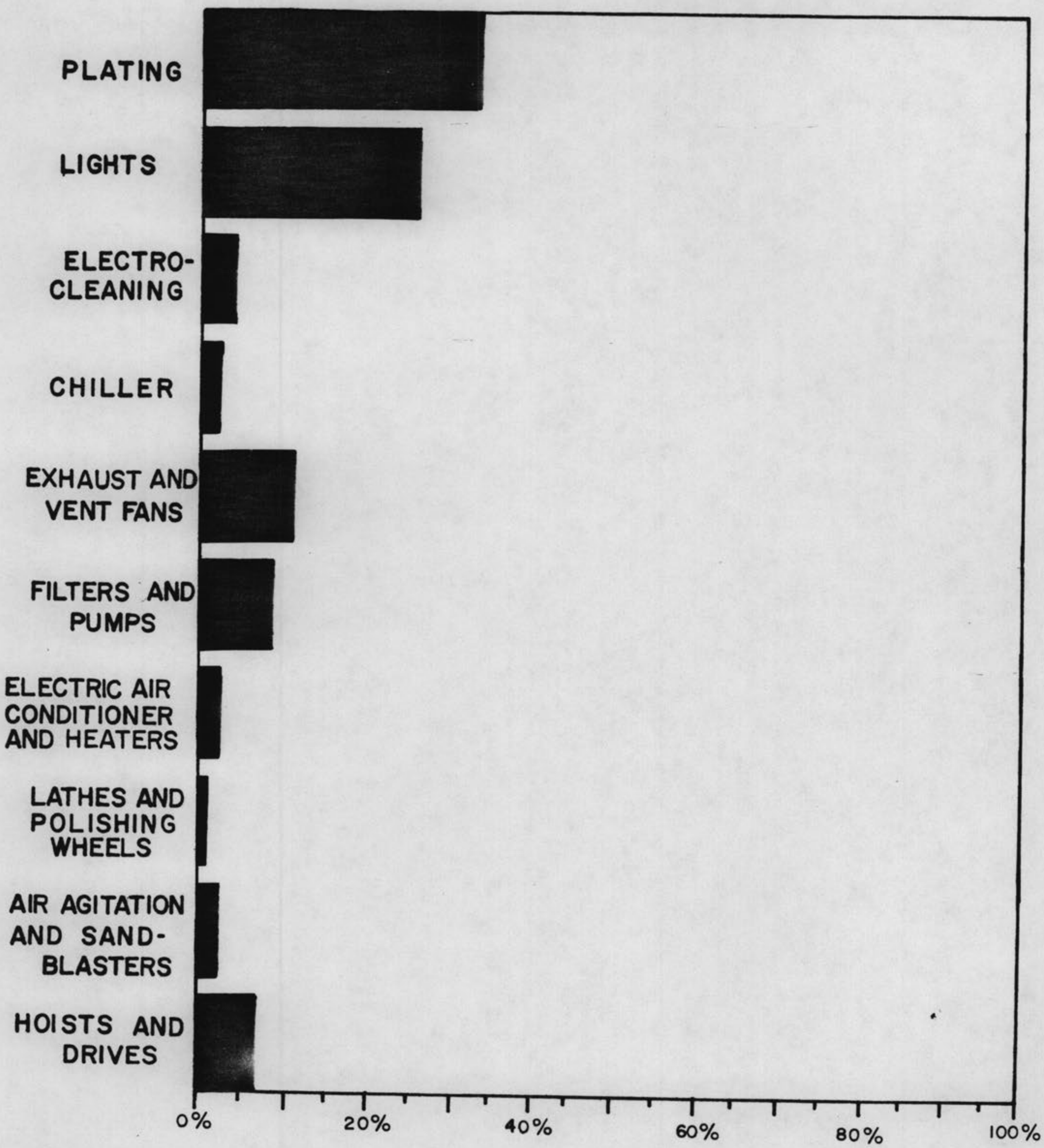
		Percent of total
1.	Plating	33.0
2.	Lights	26.0
3.	Electrocleaning	4.0
4.	Chiller	2.5
5.	Exhaust fans	11.4
6.	Filters and pumps	8.2
7.	Air conditioners and heaters	3.0
8.	Lathes and polishing wheels	1.3
9.	Air agitation blowers and sand blaster	3.0
10.	Hoists and drives	6.6
		100.0%

Process Heat Energy Usage Breakdown

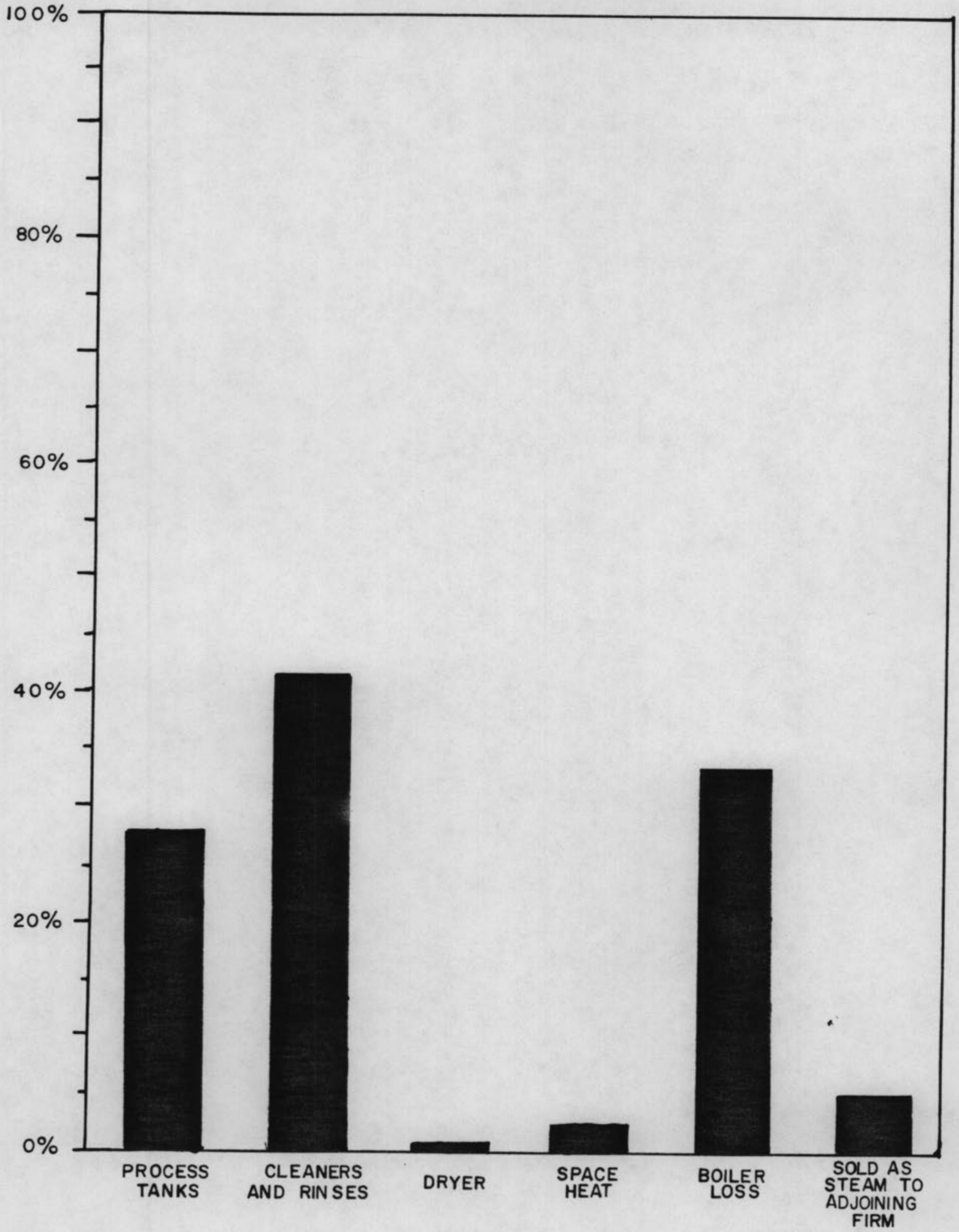
Total annual BTU's 2.46×10^{10}

		Percent of total
1.	Process Tanks	27.7
2.	Cleaners and rinses	41.4
3.	Dryer	.9
4.	Space heat	2.1
5.	Boiler losses	23.0
6.	Sold as steam to adjacent firm	4.9
		100.0%

BREAKDOWN OF ELECTRICAL USAGE IN PLANT J



BREAKDOWN OF PROCESS HEAT ENERGY USAGE IN PLANT J



Plant K Energy Profile

Electrical Energy Usage Breakdown

Total annual kilowatt-hours 1.95×10^6

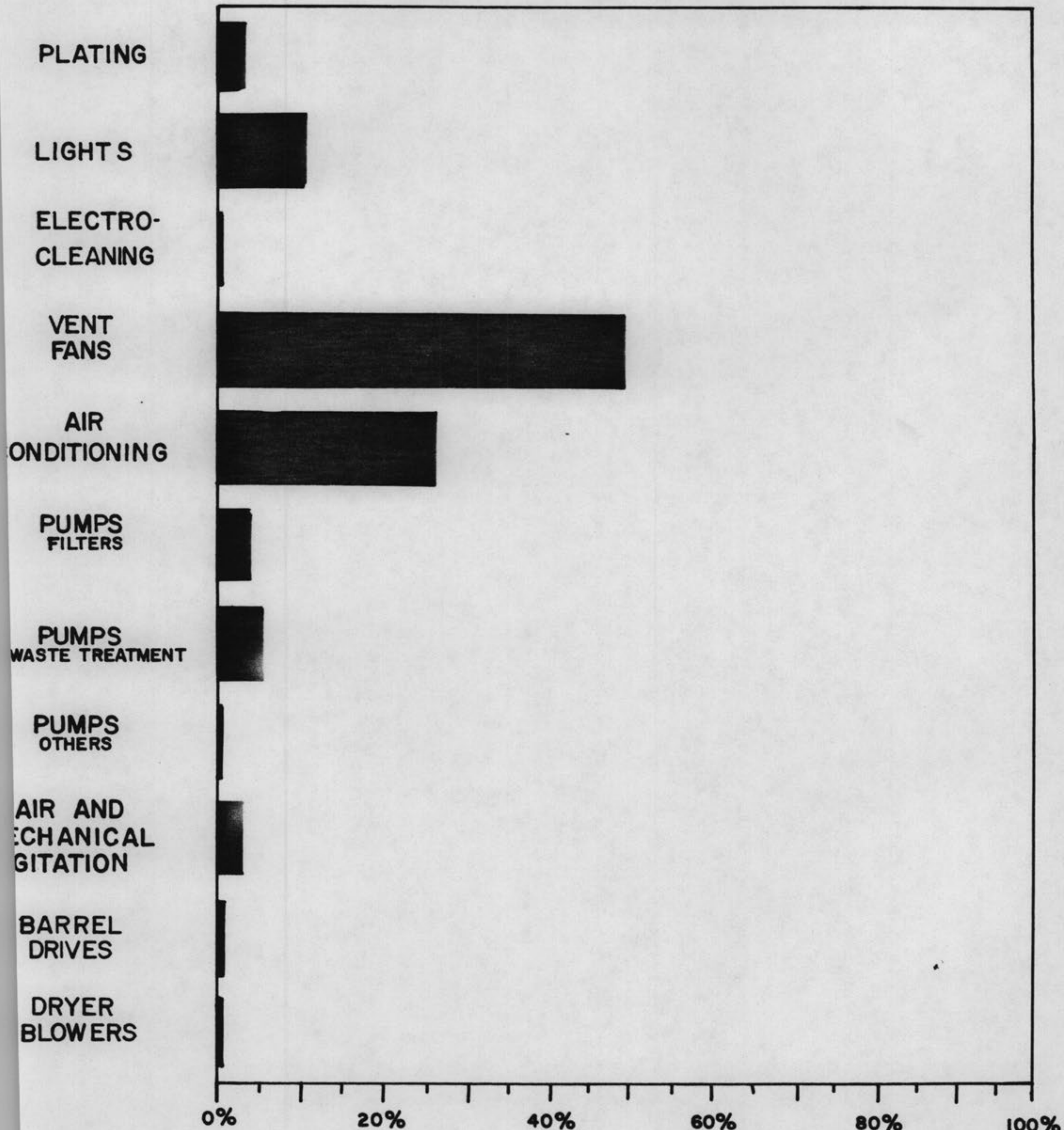
	Percent of total
1. Plating	2.8
2. Lights	9.9
3. Electrocleaning	.5
4. Vent fans	49.1
5. Air conditioning	25.2
6. Pumps; Filter	3.7
7. Waste treatment	4.9
8. Others	.4
9. Air and mechanical agitation	2.5
10. Barrel drives	.6
11. Dryer blowers	.4
	100.0%

Process Heat Energy Usage Breakdown

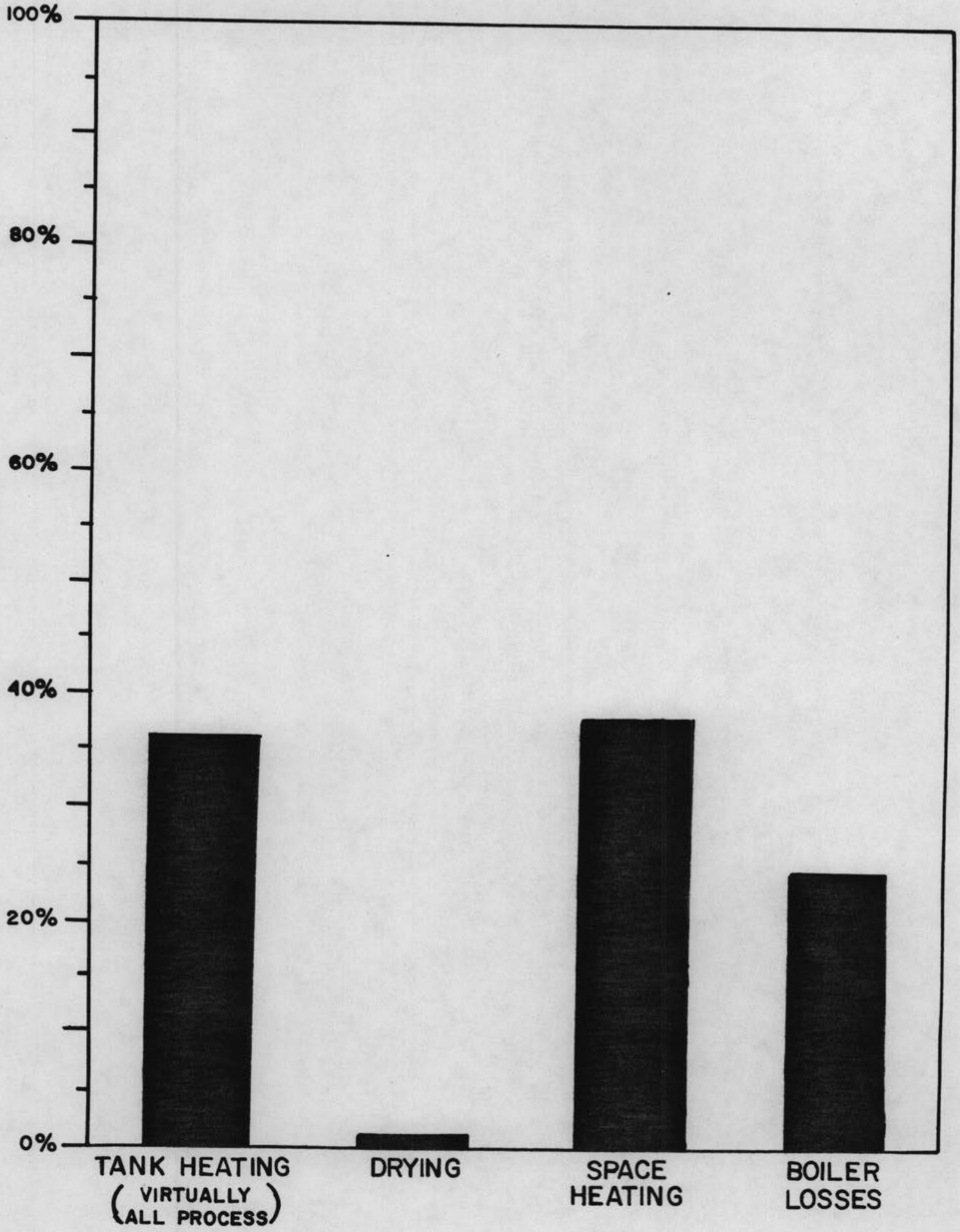
Total annual BTU's 1.44×10^{10}

	Percent of total
1. Tank heating (virtually all process)	36.3
2. Drying	1.3
3. Space heating	37.8
4. Boiler losses	24.7
	100.0%

BREAKDOWN OF ELECTRICAL ENERGY USAGE IN PLANT K



BREAKDOWN OF PROCESS HEAT ENERGY USAGE IN PLANT K



Plant L Energy Profile

Electrical Energy Usage Breakdown

Total annual kilowatt-hours 7.06×10^6

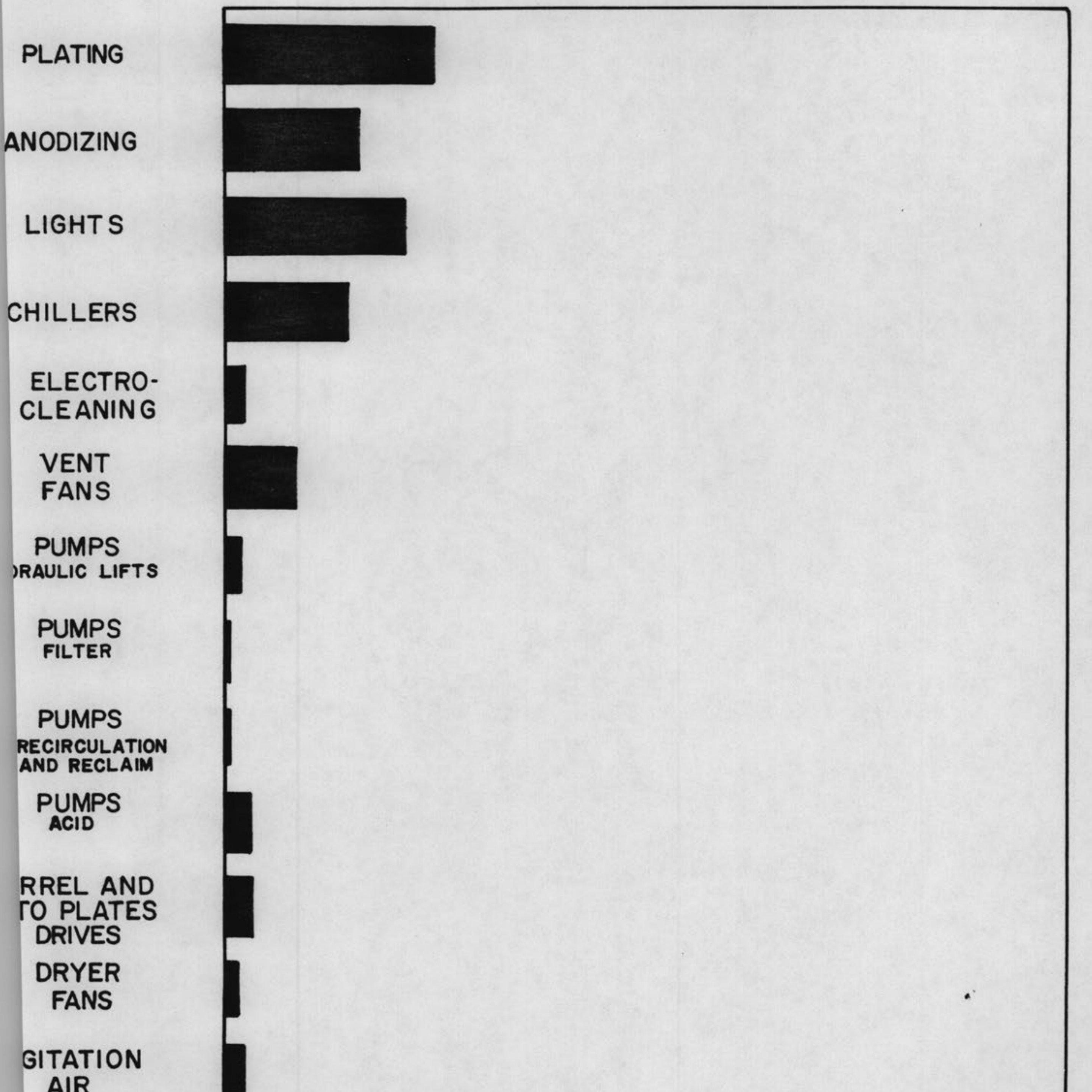
		Percent of total
1.	Plating	24.9
2.	Anodizing	15.1
3.	Lights	21.0
4.	Chillers	14.8
5.	Electrocleaning	2.1
6.	Vent fans	8.8
7.	Pumps: hydraulic lift	2.0
8.	filter	.7
9.	recirculating and reclaim	1.0
10.	acid	3.1
11.	Barrel and auto plater drives	3.2
12.	Dryer fans	1.3
13.	Agitation air	2.0
		100.0%

Process Heat Energy Usage Breakdown

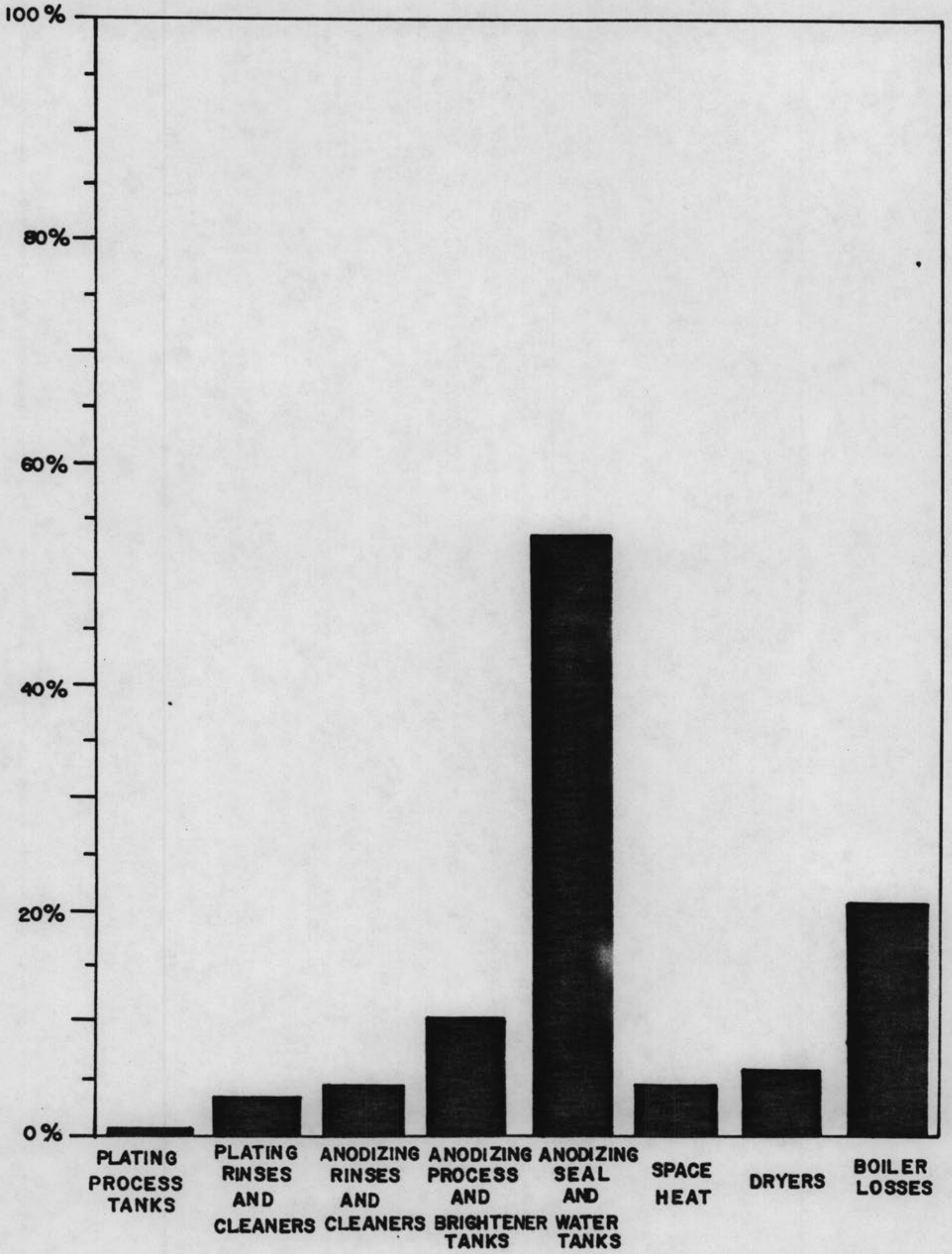
Total annual BTU's 4.69×10^{11}

		Percent of total
1.	Plating process tanks	.4
2.	Plating rinses and cleaners	2.9
3.	Anodizing rinses and cleaners	4.3
4.	Anodizing process and brightener tanks	10.0
5.	Anodizing seal water tanks	52.8
6.	Space heat	4.3
7.	Dryers	5.2
8.	Boiler losses	20.1
		100.0%

BREAKDOWN OF ELECTRICAL ENERGY USAGE IN PLANT L



BREAKDOWN OF PROCESS HEAT ENERGY USAGE IN PLANT L



Plant M Energy Profile

Note: The substantial painting facilities at Plant M are included.

Electrical Energy Usage Breakdown

Total annual kilowatt-hours 1.50×10^6

	Percent of total
Plating Area	
1. Plating	6.8
2. Lights	14.3
3. Electrocleaning	.6
4. Electropolishing (stainless)	1.4
5. Vent fans	26.9
6. Pumps: waste treatment	2.3
7. filter and recirculating	1.1
8. parts washer spray	2.8
9. Tumbling	.4
10. Chillers	1.7
11. Barrel, spin dryer drives and hoists	1.4
12. Electric heat treat oven	1.1
13. Dry off and oven fans	1.5
Paint Area	
14. Pumps: spray	7.2
15. recirculating	13.4
16. Oven fans (bake and dry off)	3.3
17. Paint cooler compressors	11.8
18. Drivers and mixer	1.4
19. Air make-up fans	.6
	100.0%

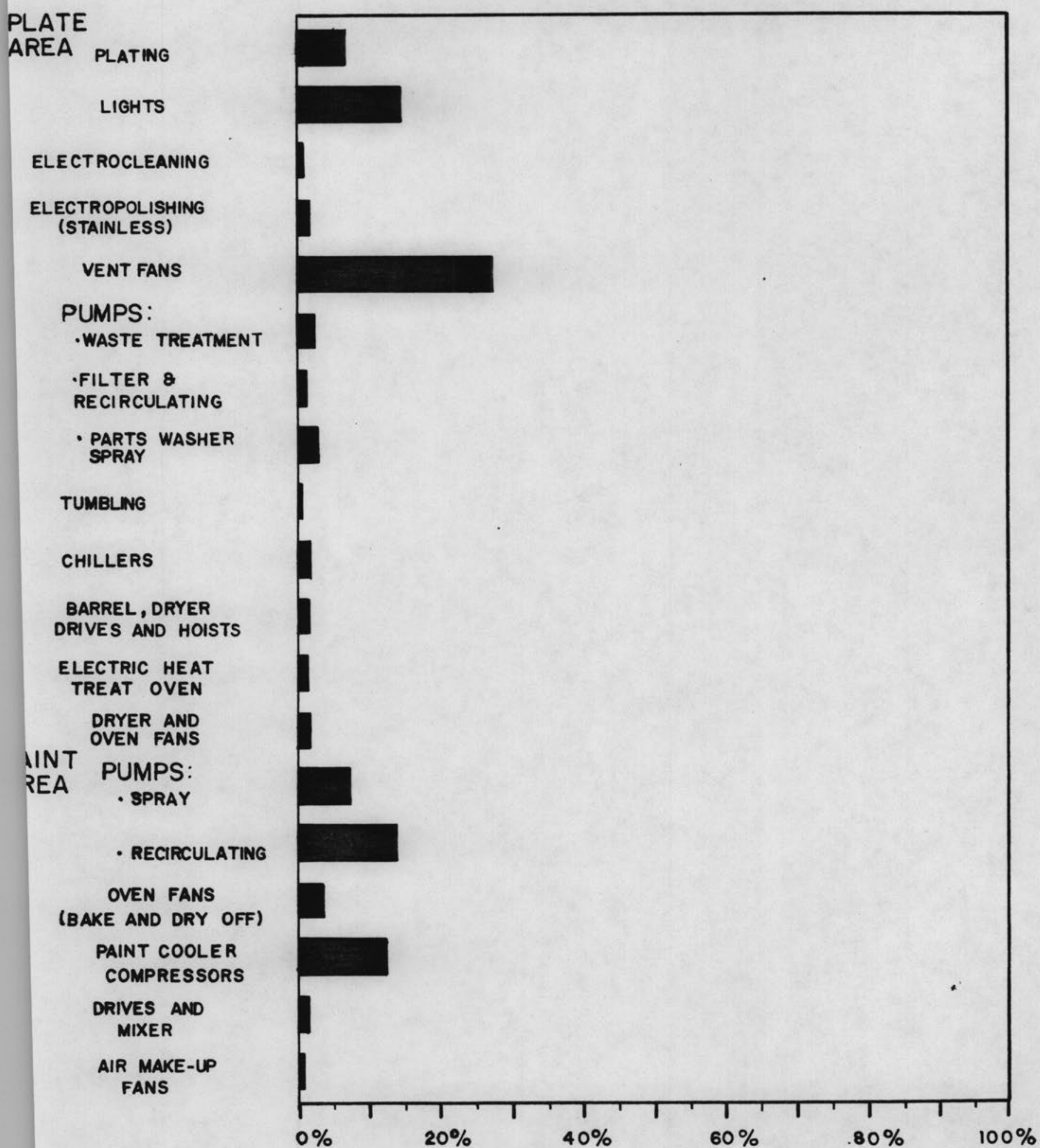
Plant M (continued)

Process Heat Energy Usage Breakdown

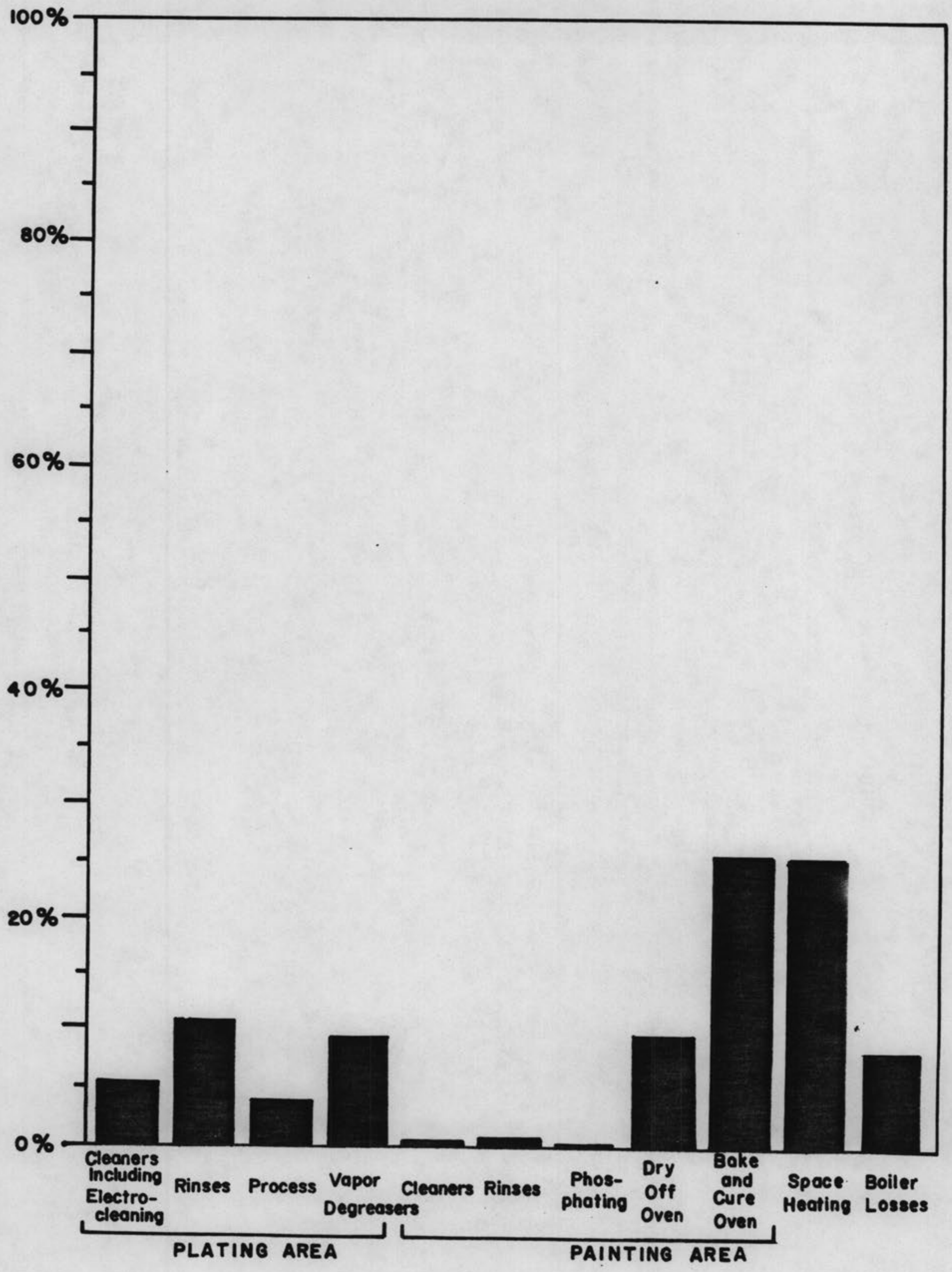
Total annual BTU's 3.76×10^{10}

	Percent of total
Plating Area	
1. Cleaners including electrocleaning	5.5
2. Rinses	10.5
3. Process	4.2
4. Vapor degreasers	9.3
Painting Area	
1. Cleaners	.5
2. Rinses	.6
3. Phosphating	.2
4. Dry off oven	9.8
5. Bake and cure oven	25.5
6. Space heating	25.3
7. Boiler losses	8.6
	100.0%

BREAKDOWN OF ELECTRICAL ENERGY USAGE IN PLANT M



BREAKDOWN OF PROCESS HEAT ENERGY USAGE IN PLANT M



Energy Profile Plant N

Electrical Energy Usage Breakdown

Total annual kilowatt-hours 1.71×10^6

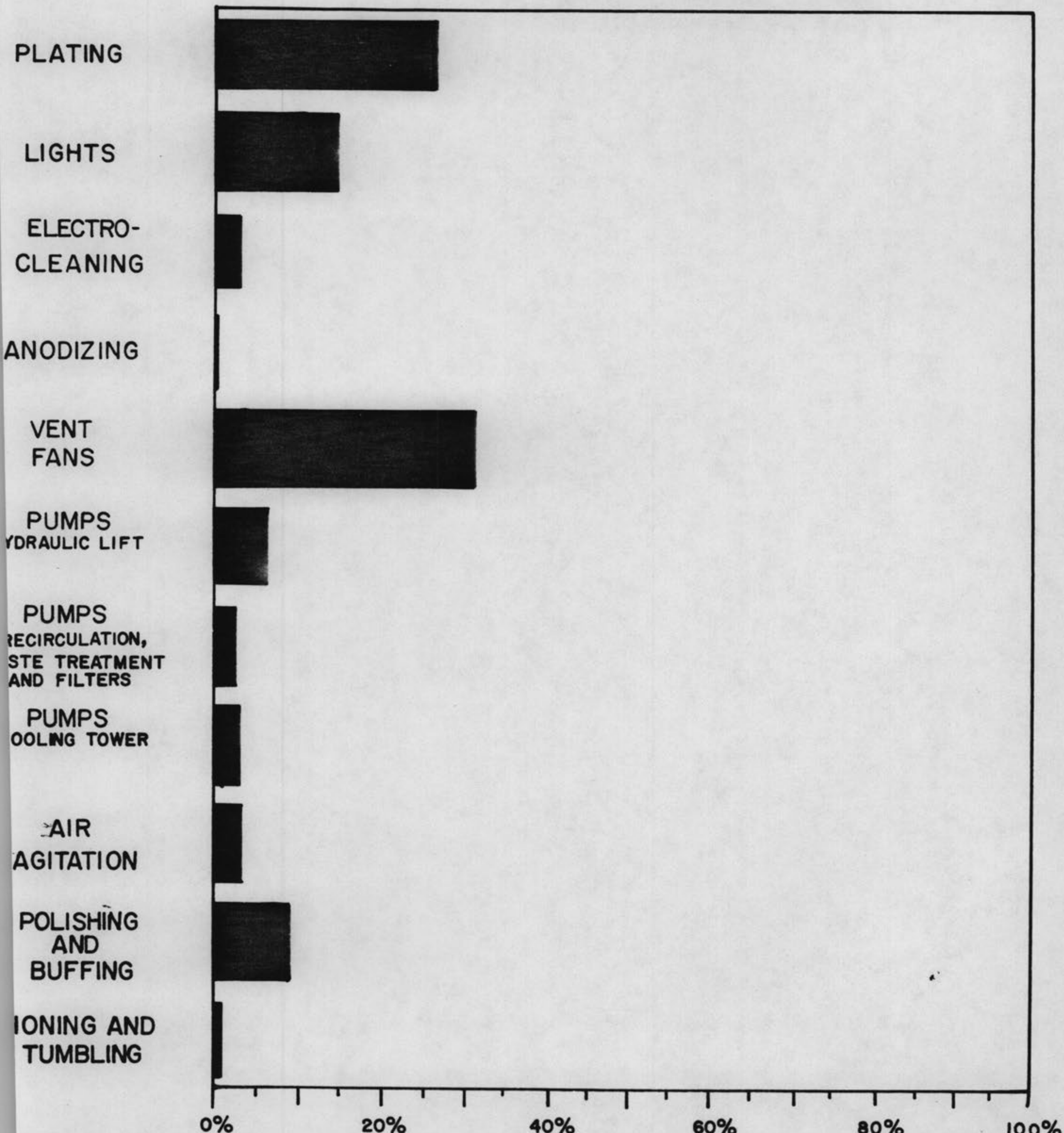
		Percent of total
1.	Plating	26.4
2.	Lights	14.7
3.	Electrocleaning	2.8
4.	Anodizing	.2
5.	Vent fans	31.3
6.	Pumps: hydraulic lift	5.9
7.	recirculating, waste treatment and filters	2.3
8.	cooling tower	2.8
9.	Air agitation	3.1
10.	Polishing and buffing	9.5
11.	Honing and tumbling	1.0
		100.0%

Process Heat Energy Usage Breakdown

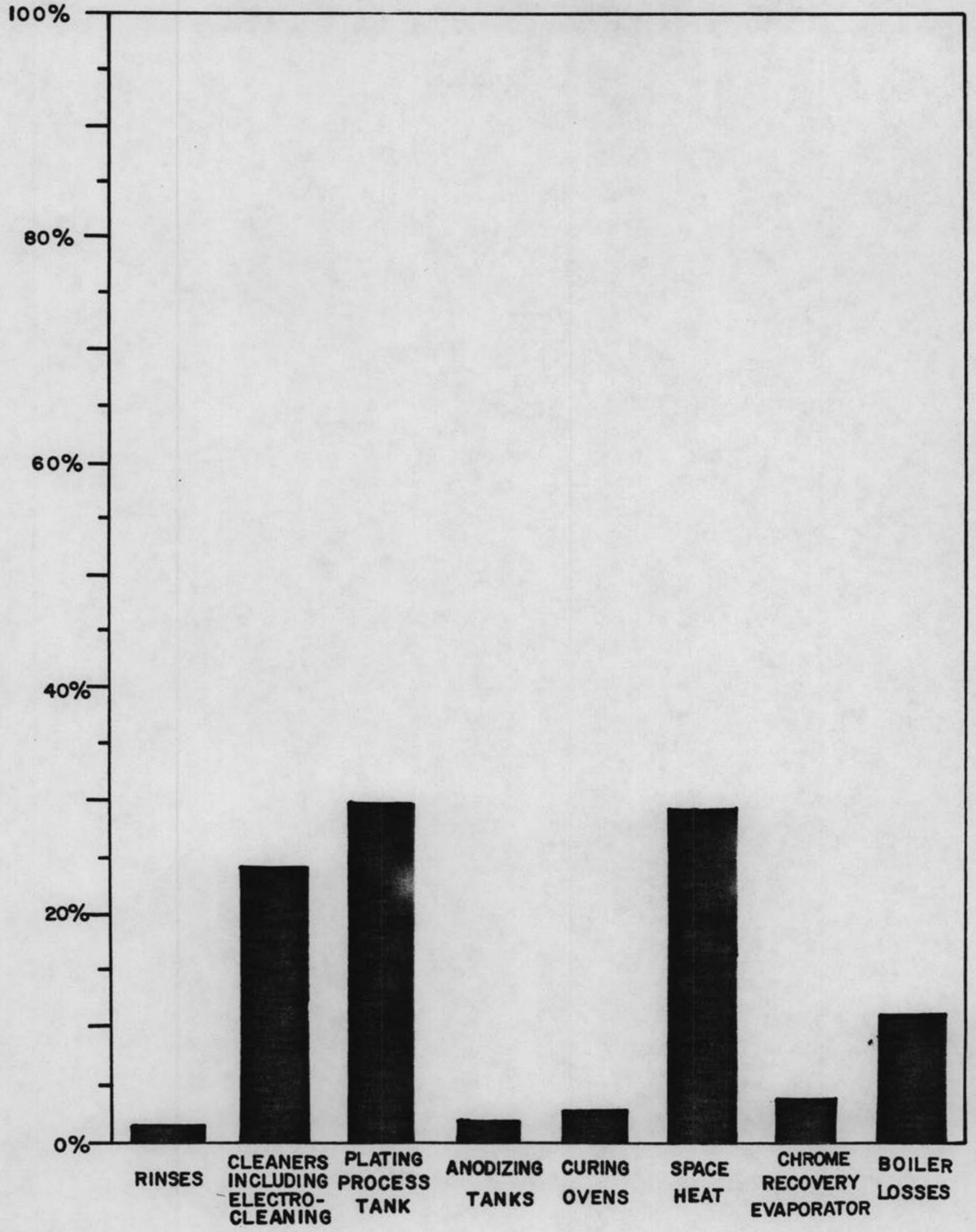
Total annual BTU's 3.15×10^{10}

		Percent of Total
1.	Rinses	1.1
2.	Cleaners including electrocleaners	23.7
3.	Plating process tanks	29.8
4.	Anodizing tanks	1.6
5.	Curing ovens	2.0
6.	Space heat	28.8
7.	Chrome recovery evaporator	2.6
8.	Boiler losses	10.4
		100.0%

BREAKDOWN OF ELECTRICAL ENERGY USAGE IN PLANT N



BREAKDOWN OF PROCESS HEAT ENERGY USAGE IN PLANT N



Energy Profile Plant O

Electrical Energy Usage Breakdown

Total annual kilowatt-hours 9.06×10^5

		Percent of total
1.	Plating	41.1
2.	Lights	8.6
3.	Electrocleaning	4.3
4.	Exhaust fans	16.0
5.	Polishing, buffing	5.0
6.	Blowers; air agitation, dryer, boiler	6.1
7.	Filters	10.3
8.	Air compressors (drive hoists)	8.2
9.	Wash pump	.4
		100.0%

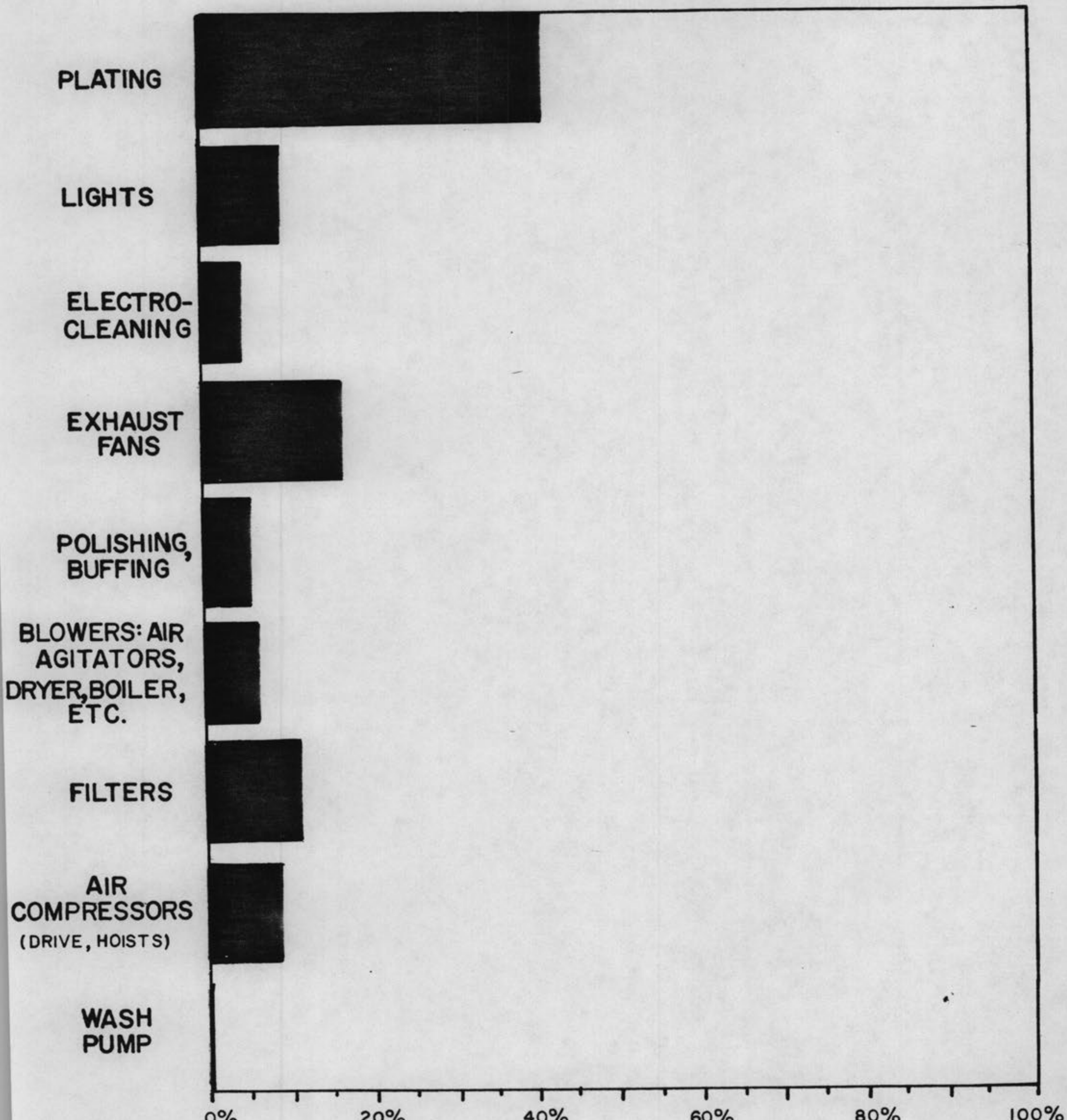
Process Heat Energy Usage Breakdown

Total annual BTU's 1.42×10^{10}

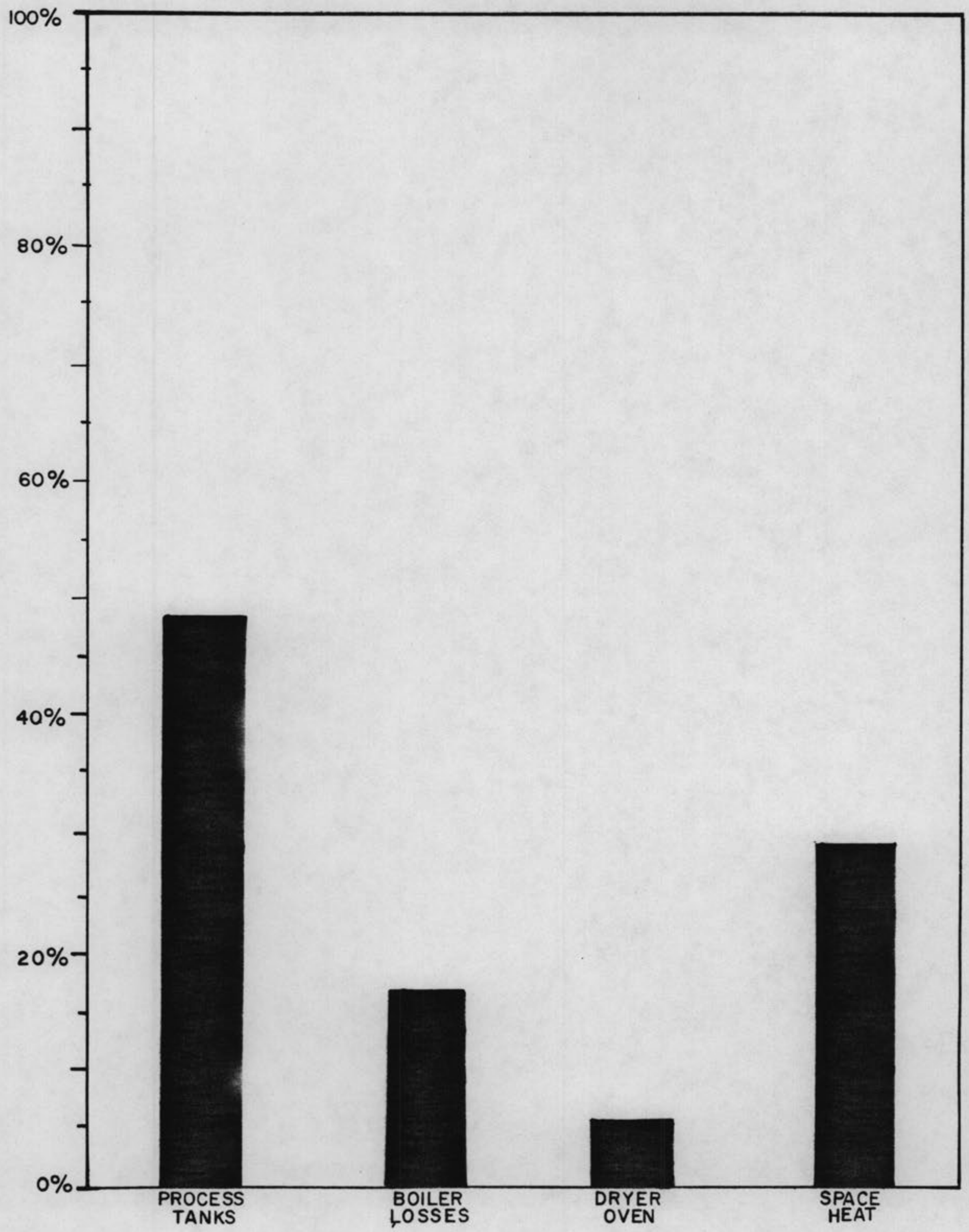
		Percent of total
1.	Process tanks	48.5
2.	Boiler losses	16.2
3.	Dryer oven	5.7
4.	Space heat	29.7
		100.0%

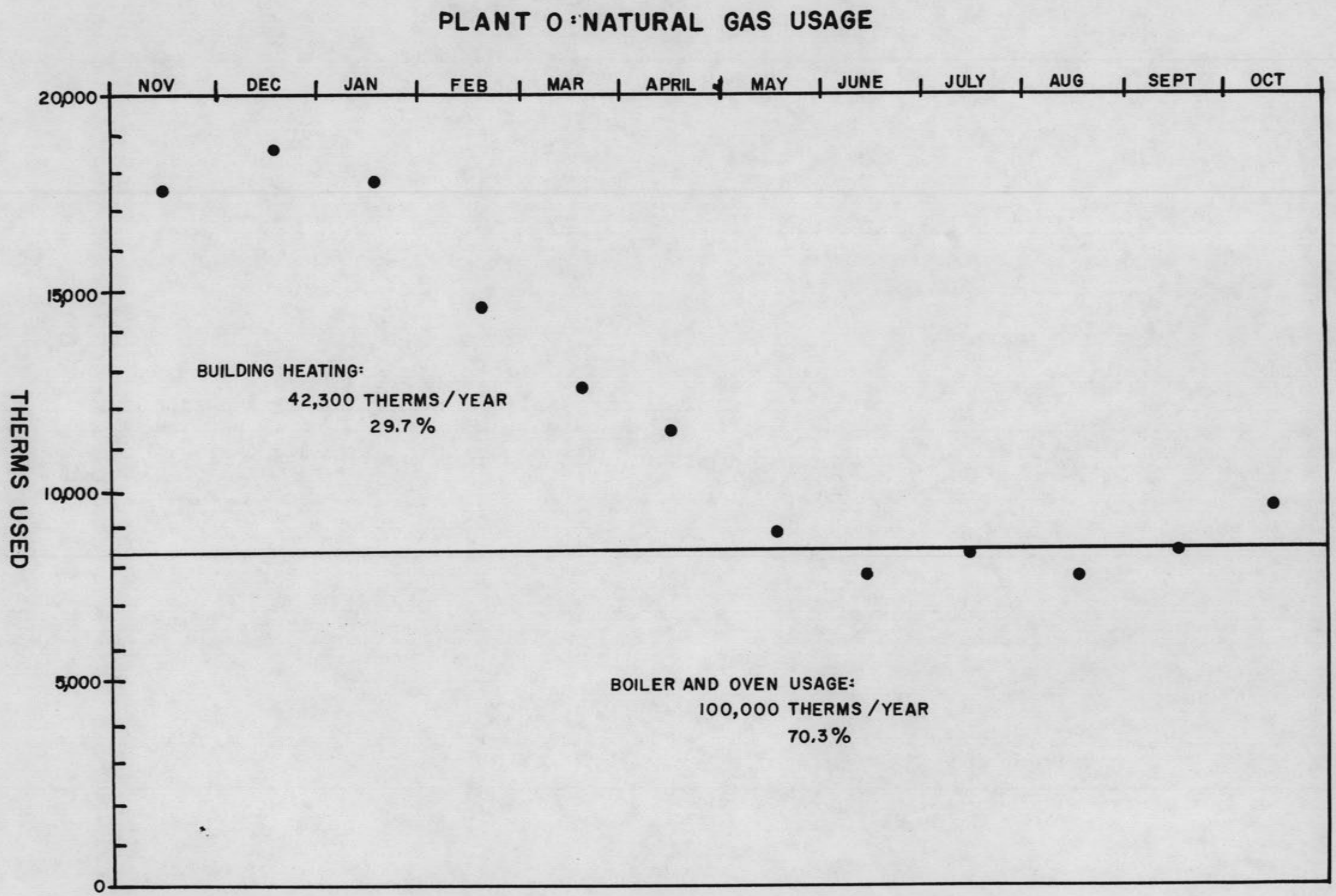
Note: All cleaners and rinses are ambient.

BREAKDOWN OF ELECTRICAL USAGE IN PLANT O



BREAKDOWN OF PROCESS HEAT ENERGY USAGE IN PLANT O





PLANT O: NATURAL GAS USAGE
NOV
DEC
JAN
FEB
MAR
APRIL
MAY
JUNE
JULY
AUG
SEPT
OCT
20,000
15,000
10,000
5,000
0
THERMS USED
BUILDING HEATING:
42,300 THERMS / YEAR
29.7 %
BOILER AND OVEN USAGE:
100,000 THERMS / YEAR
70.3 %

APPENDIX B

EXAMPLE CALCULATIONS

Electrical Usage - Plating

Apply Faraday's Law in the following form:

$$\text{grams deposited} = \frac{\text{Molecular Wt X Energy consumed (calories)}}{\text{Molar equivalent X 23,060 } \frac{\text{cal}}{\text{volt e.g.}} \text{ X voltage applied}}$$

For example zinc:

$$(36{,}000 \text{ lbs}) \ 454 \text{ grams/lb} = \frac{65.4 \text{ X (calories)}}{2 \text{ x } 23{,}060 \text{ X } 7.5}$$

Where 7.5 volts is the average applied, half at 3 volts rack plating and half at 12 volts barrel plating. This is the approximate work distribution.

The calories delivered are then

$8.6 \text{ X } 10^{10}$ cals

assuming a 72 percent overall efficiency for rack plating and 40 percent for barrel plating and converting to kwhs:

$$8.6 \text{ X } 10^{10} \text{ cals } \frac{2}{(.72 + .40)\text{eff}} \text{ X } 1.16 \text{ X } 10^{-6} \text{ kwhs/cal} =$$

$1.75 \text{ X } 10^{5}$ kwhs consumed.

Lighting

A plating shop has 10,750 watts of fluorescent lighting and 3500 watts of incandescent lighting operating 5 days a week 20 hours a day. The energy consumed is then

(10,750 watts)(1 kw/1000 watts)(20 hrs/da)(5 da/wk)(52 wk/yr) =

55900 kwhs/yr

add 20% to drive the lighting ballast

(55900) 1.2 = 67,100 kwh/yr.

(3500)(1 kw/1000 watts)(20 hr/da)(5 da/wk)(52 wk/yr) =

18,200 kwh/yr

The sum of the two usages gives the total plant lighting consumption as 85,300 kwhs/yr.

Electrocleaning

Energy consumption for two electrocleaning stations is calculated as follows:

#1	300 amps @ 6 volts	120 hrs/wk
#2	1000 amps @ 9 volts	60 hrs/wk

#1 (300 amp)(6v)(120 hrs/wk)(1 kw/1000 watts)(50 wk/yr) =

10,800 kwhs/yr

#2 (1000 amp)(9v)(60 hrs/wk)(1 kw/1000 watts)(50 wk/yr) =

27000 kwhs/yr

For a total of 37,800 kwhs/yr.

Motors

A 25 hp air compressor motor draws 50 amps on each leg of a 3 phase circuit at 220 volts. The unit runs 10 hours a day, 52 week a year, 5 days a week.

(220 volts) (50 amps)(1.732)(10 hrs/da)(5 da/wk)(52 wk/yr)(1 kw/1000 watts) =

(1 kw/1000 watts) = 49500 kwhs/yr

Process Heat Usage - Tank Heating

A plating tank is maintained at 180°F 24 hours a day, 5 days a week. The tank dimensions are 6' long by 4' wide by 4' deep. No direct ventilation is provided. Heating is by steam at 15 psi through coils. Condensate is not returned.

Heat loss from the tank surface will be approximately:

(2100 Btu/hr ft^2)(24 ft^2)(24 hrs/da)(5 days/wk)(52 wks/yr) =

3.14×10^8 Btu/yr.

where the evaporative heat transfer coefficient of 2100 Btu/hr ft^2 has been taken from "Heat Losses from Tanks, Vats and Kettles", by Samuel J. Friedman April 1948.

The tank walls and bottom have an average heat transfer coefficient of 2.1 Btu/hr ft^2 °F, then

(2.1 Btu/hr ft^2 °F)(104 ft^2)(180° - 70°F)(24 hrs/da)(5 da/wk)(52 wk/yr =

1.50×10^8 Btu/yr

where the combined radiative and corrective heat transfer coefficient of 2.1 Btu/hr ft^2 °F has been taken from "Mark's Handbook" 7th edition copyright 1969.

The total Btu's needed then to heat this tank are:

$$(3.14 + 1.50) \times 10^8 \text{ or}$$

$$4.64 \times 10^8 \text{ Btu/yr.}$$

In addition to these direct energy losses, the steam condensate which is not returned to the boiler represents another energy loss associated with heating this tank. For one pound of steam at 15 psi the heat content of the steam is 1134 Btu/lb (from the international steam tables) and the sensible heat available above the ambient water temperature of 60° is 152 Btu/lb. Thus, the hot condensate contains

$$\frac{152}{1134}\ 100 = 13\% \text{ of the}$$

total available heat, which is not effectively used. The total then of 4.64×10^8 Btu is 100-13 = 87% of the actual consumption. Or to heat this tank consumes approximately.

$$\frac{4.64 \times 10^8}{.87} = 5.33 \times 10^8 \text{ Btu/yr.}$$

A-2042

Final Report

ENERGY CONSERVATION STUDY OF THE PLATING AND SURFACE FINISHING INDUSTRY

By

Daniel A. Mazzeo, Project Director
Wiley D. Holcombe, Contributing Author

October, 1978

GEORGIA INSTITUTE OF TECHNOLOGY

Engineering Experiment Station
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SUMMARY

The American plating and surface finishing industry currently uses an estimated fifty-two million barrels of oil equivalent energy annually. This report focuses on the quantitative breakdown of energy usage in twenty electroplating facilities, on methods for conserving that energy and on the energy saving potential in each area.

The total annual electrical energy usage for the twenty plants is 5.30×10^7 kwh with the largest energy consumers being exhaust fans, plating and/or anodizing and lighting respectively. The total annual process heat usage is 1.08×10^{12} Btu with the largest energy consumers being tank heating, boiler losses and space heat. These areas provide opportunities for energy savings. Methods for achieving these savings are outlined in the report.

In addition, several other pertinent areas are investigated. A technique for bus bar optimization, which balances energy and capital costs, is presented. The relative economics for using blowers versus air compressors for air agitation are presented.

I. INTRODUCTION

The American plating and surface finishing industry currently uses an estimated 52 million barrels of oil equivalent energy annually. Plating and surface finishing operations are ancillary processes in many major industries, such as the automotive, electronics, aircraft and fastener industries. The industry is composed of approximately 12-13,000 plating and surface finishing facilities throughout the United States, which range from very large facilities that are segments of major manufacturers to small, independently owned contract shops.

Regardless of the size or degree of sophistication, each facility utilizes basically the same processes in plating and surface finishing. First, the base material must be prepared. This is generally done through a series of cleaners, chemical treatments, and rinses. These processes can be either hot or cold, depending on the type of contaminant, treatment, etc., and perform the function of removing or diluting the contaminant to an acceptable level.

Once the base material is prepared it is generally submerged in an electrolyte, where direct current is applied between an anode and a cathode to drive the plating process. After the process is complete, the finished product is rinsed to remove residual electrolyte and dried. All of these processes require energy. Alternate processes for anodizing, conversion coating and surface coloring use similar type operations and also require energy.

Additionally, the environmental conditioning of the facility for worker safety and comfort requires the use of large amounts of energy. Exhaust systems are often required to draw off toxic or noxious fumes from the process tanks, degreasers, spray booths, and dryer ovens. Heat from these processes must be removed or dissipated to allow workers reasonable comfort. Many of these environmental systems in themselves contribute to or increase the energy requirements for the operations of open rinse tanks, process tanks, degreasers, ovens and space conditioning among other items.

Over the last few years, environmental considerations have increased energy usage in plating and surface finishing facilities. Waste water flow from the plants must be treated to remove objectionable materials before effluent discharge. In order to reduce treatment costs, some chemical concentrations have been reduced. This requires greater voltages for plating and surface finishing, or longer dwell times for the base material. In either case, energy requirements have increased. In addition, waste treatment system energy requirements increase with increasing volumetric flow and pollutant concentration.

Data from the 1972 Census of Manufacturers indicates that during 1971 the plating and surface finishing industry used over 6,646,000 barrels-of-oil equivalent. However, results of this study indicate the actual use in 1977 was approximately 8 times greater, or about 52 million barrels-of-oil equivalent. (See Appendix G) This is true first, because census data does not include captive shops, which are components of larger industrial operations and second, because of industry growth. Of this 52 million barrels-of-oil equivalent, our data indicates that 86 percent was consumed as natural gas in processes such as steam boilers and dryers. Approximately 14 percent was used as electricity for materials handling, environmental conditioning, and in plating and surface finishing processes themselves. Georgia Tech's experience with other industries, such as poultry processing, indicates that at least a 20 percent reduction in total energy consumed can be realized from a well researched and broadly implemented program of energy conservation.

This program has as one of its objectives the thorough investigation of energy use patterns in existing plating and surface finishing plants. By monitoring representative facilities, we have compiled data on the energy consumption of the various processes utilized. During these visits, in addition to acquiring energy usage data, we have gathered ideas from engineers and other personnel as to proven and conceptualized energy conservation techniques. Evaluation of various methods to reduce energy use has been undertaken, with technical advice and overview from the industry provided through the American Electroplaters' Society (AES). Some energy saving modifications require theoretical optimization techniques, and these are being addressed. However, it is anticipated that field applications in cooperating plants and surface finishing facilities will be required to validate the optimization procedures. It has also been our experience that the more advanced and more costly energy conserving modifications have been reluctantly adopted by industry members until they have been proven in a production facility. Therefore, in later phases of this research we hope to demonstrate actual energy conserving modifications and to develop and optimize empirical energy conserving methods in actual production plating and surface finishing situations. Dissemination of the results of this program will be accomplished by AES through its established communication channels.

The American Electroplaters' Society is a technical society of those engaged in the plating and surface finishing industry. As such, it carries on an active program of research that has as a general goal the betterment and improvement of the industry. The Society's research is supported by individual members and member firms. Current AES research includes programs such as "Treatment of Electroplating Wastes by Reverse Osmosis," "Optimization of Barrel Plating Solutions," and "The Application of Pulsed Plating Techniques to Metal Deposition". These research programs are conducted by universities or private research organizations. AES representatives approached Georgia Tech with the concept for this research. This joint effort between Georgia Tech and AES resulted.

To accomplish the purposes of this research, five broad tasks have been defined:

Task I:	to identify energy consuming processes in the plating and surface finishing industry.
Task II:	to establish the amounts of energy used in each process, and to determine the mechanisms by which energy is consumed.
Task III:	to develop energy saving modifications and modified operational procedures for energy intensive processes to reduce consumed energy.
Task IV:	to estimate the energy saving potential for each process or procedural modification.
Task V:	to disseminate the developed energy saving modifications and operational procedures throughout the industry for implementation.

The initial task of identifying energy consuming processes in the plating and surface finishing industry started with a survey of twenty representative facilities, selected with the aid of the American Electroplaters' Society. This survey consists of an energy audit of each of the facilities visited, noting the contribution of each process to total energy consumption. The results are contained in Appendix A. Each plant is referred to by an assigned letter to maintain confidentiality. Of the twenty plants, eleven are job shops, nine are captive shops. Some data on plant size and characteristics is included as an aid to other plating facilities in relating to the energy usage data.

The plating plants surveyed process a very wide range of plated products. Screws, nuts and bolts, staplers, scissors, aircraft and automotive parts, electronic parts and circuitry, appliances large and small, furniture hardware, and locks are some of the items handled by these plants. Plating practices vary just as widely, as do priorities and thus attitudes toward energy and energy conservation.

Of the twenty plants surveyed, eleven had done nothing or very little to investigate or implement energy conservation measures at the time of the plant visit. Four had done something in the way of energy conservation, if however small. Four others had taken action on several energy conservation items, and one plant had implemented numerous energy conservation items with very satisfactory results. In most cases energy is not the plants' highest operational expense. It is second or third behind labor and materials and thus, does not receive a great deal of attention. Capital money for energy saving measures has had to compete most often with new production equipment and pollution control equipment among other items.

II. ENERGY CONSUMING PROCESSES AND MECHANISMS OF ENERGY CONSUMPTION

The plating and surface finishing plants surveyed consume energy in the basic forms of electricity and fossil fuel. Electricity is consumed in the following ways:

1. Rectification - for plating, anodizing, electrocleaning.
2. Lighting - to illuminate the plant environment.
3. Electric motors - to perform a wide variety of functions in such equipment as:
    a. Exhaust fans
    b. Pumps
    c. Filters
    d. Blowers
    e. Air compressors
    f. Chillers
    g. Buffing machines
4. Tank heating - many plants have electric immersion heaters, most tank heating, however, is done via fossil fuels.
5. Vapor degreasers - the heating elements in vapor degreasers are often electric.
6. Ovens - several plants use electric ovens for heat treating.

Fossil fuel usage in the plants surveyed is almost exclusively natural gas. Propane and fuel oil are maintained as standby fuels in a few of the plants surveyed but their usage is minimal. The fossil fuels are consumed in the following areas:

1. Tank heating - for process, rinsing and cleaner tanks usually as steam generated in a boiler. Occasionally a tank is heated by direct firing of natural gas beneath the tank. This practice is, however, rare.
2. Ovens and Dryers - ovens which use natural gas as their fuel source are direct fired. Dryers may be direct fired or heated via steam.

3. Vapor degreasers - steam is sometimes used in the boiling of the degreaser solvent and also in the recovery stills which evaporate the solvent for reclaim and reuse.

4. Space heating - plant heating is most often accomplished by direct firing of natural gas into the plant make-up air stream, as it enters the plant. Direct fired radiant heaters and steam fed heaters are also used.

5. Evaporators - used to recover plating solutions, usually chromium, for reuse; steam fed.

6. Boiler losses - a considerable amount of energy is lost with the escaping boiler stack gases.

III. QUANTITIES OF ENERGY CONSUMED IN PLATING OPERATIONS

A detailed energy audit, estimating the amount of energy used in each operation, has been performed for each of the twenty survey plants. The individual plant results are contained in Appendix A. The energy audits are based on one year of operation. Specifically, the twelve months preceeding the plant audit were used. Electrical energy consumption ranged from 3.03×10^5 kwhs/yr to 1.31×10^7 kwhs/yr with an average of 2.65×10^6 kwhs/yr. Process heat energy consumption ranged from 1.04×10^9 Btu/yr to 4.69×10^{11} Btu/yr with an average of 5.38×10^{10} Btu/yr. These figures need be qualified in that they include some usages not strictly related to plating. For instance, the painting operations at Plant M are included as is the injection molding department at Plant Q. This, however, will not change our conclusions.

The following Tables 1 and 2 contain average results for all plants surveyed for electrical and process heat energy usage.

TABLE 1

Average Electrical Energy Consumption for All Plants

Total Annual Kilowatthours	5.30×10^7
Average Annual Kilowatthours Per Plant	2.65×10^6

	Percent of total
1. Exhaust fans	24.6
2. Electroplating and/or anodizing	23.9
3. Lighting	11.7
4. Hoists and drives	5.0
5. Oven heat	4.5
6. Filter pumps	3.0
7. Electric tank heating	2.9
8. Waste treatment equipment	2.7
9. Air agitation	2.7
10. Chillers	2.6
11. All other pumps	2.6
12. Grinding, polishing, buffing	2.4
13. Electrocleaning	2.4
14. Air-conditioning	2.3
15. Other uses	6.7
	100.0%

TABLE 2

Average Process Heat Energy Consumption

All Plants

Total Annual Btu's	1.08×10^{12}
Average Annual Btu's Per Plant	5.38×10^{10}

	Percent of total
1. Process tank heating	23.1
2. Boiler losses	18.2
3. Space heat	18.2
4. Cleaner tank heating	12.0
5. Rinse tank heating	10.0
6. Ovens and dryers	7.0
7. Vapor degreaser heaters and stills	4.0
8. Waste recovery evaporators	3.8
9. Other uses	3.7
	100.0%

Electrically the largest consumers are exhaust fans, plating and anodizing, and lighting. These three categories consume 60.2% of the total electrical energy usage. Process heat energy consumption is greatest in the area of tank heating. Note that all tank heating amounts to 45.1% of the total. Boiler losses and space heat consume the next largest amounts.

The above treatment of the data does not reveal the two patterns of energy usage which have emerged. Sixteen plants in this pattern group anodize aluminum and/or plate zinc, copper, nickel and chromium, among other metals, in large quantities for decorative purposes and corrosion protection. Tables 3 and 4 contain average energy usages for these plants. Plating is the highest single consumer of electrical energy. Exhaust fans and lighting are second and third highest consumers of electrical energy. Thus, electrically, this pattern group is largely similar to the results for all plants. Process heat usage differs in one significant area, space heat. Plants in this first pattern group consume 8.5% of their process heat energy in space heating. It is the sixth largest consumer of process heat energy. For all plants this figure is 18.2%. Space heating is the third largest consumer for all plants. In other respects this group is similar to the usages for all plants.

A second pattern group is characterized by the plating of parts that are small in size. Tables 5 and 6 contain average energy usages for these plants, which consume far less energy in actual plating than do plants in the first pattern group. Exhaust fan motors, electric tank heating, air-conditioning and lighting consume 68.1% of the electrical energy used by these plants. Space heat is the largest single consumer of heat energy in these plants. These differences are significant in ordering the priorities of these plants with respect to energy conservation projects.

TABLE 3

Average Electrical Energy Consumption;
First Pattern Group* - sixteen plants

Total Annual Kilowatthours 4.61×10^7

Average Annual Kilowatthours Per Plant 2.88×10^6

		Percent of total
1.	Electroplating and/or anodizing	29.5
2.	Exhaust fans	22.4
3.	Lighting	12.2
4.	Hoists and drives	5.9
5.	Filter pumps	3.4
6.	Grinding, polishing, buffing	3.0
7.	Electrocleaning	2.9
8.	Air agitation	2.7
9.	All other pumps	2.5
10.	Waste treatment equipment	2.2
11.	Other uses	13.3
		100.0%

*All plants except A, K, R and T

TABLE 4

Average Process Heat Energy Consumption
First Pattern Group*

Total Annual Btu's 1.05×10^{12}

Average Annual Btu's Per Plant 6.57×10^{10}

		Percent of total
1.	Process tank heat	23.3
2.	Boiler losses	19.7
3.	Cleaner tank heat	13.2
4.	Rinse tank heat	11.2
5.	Ovens and dryers	8.7
6.	Space heat	8.5
7.	Waste recovery evaporators	4.7
8.	Vapor degreaser heaters and stills	4.1
9.	Other uses	6.1
		100.0%

*All plants except A, K, R and T

It is worth noting that three of the four plants in this second pattern group are engaged in electronics related work. Although three plants may not represent an industry, the results here indicate that energy conservation prorities for electronics industry plating plants should be different than those for the fasteners, hardware and automotive industry platers.

Plants in the first pattern group should look to the following areas first for energy conservation opportunities:

1. Electrically
   a. Plating/anodizing
   b. Exhaust fans
   c. Lighting
2. Process heat
   a. Tank heating (all)
   b. Boiler operations
   c. Ovens and dryers
   d. Space heat

Plants in the second pattern group should look to the following areas first for energy conservation opportunities:

1. Electrically
   a. Exhaust fans
   b. Tank heating
   c. Air-conditioning
   d. Lighting
2. Process heat
   a. Space heat
   b. Tank heating (all)
   c. Boiler operations

TABLE 5

Average Electrical Energy Consumption

Second Pattern Group*

Total Annual Kilowatthours 6.92×10^6

Average Annual Killowatthours Per Plant 1.73×10^6

		Percent of total
1.	Exhaust fans	33.2
2.	Electric tank heating	14.5
3.	Air-conditioning	10.6
4.	Lighting	9.8
5.	Waste treatment	4.7
6.	Agitation air	2.3
7.	Filter pumps	2.3
8.	Hoists and drives	1.4
9.	Electroplating	1.3
10.	Other uses	19.9
		100.0%

* Includes plants A, K, R and T

TABLE 6

Average Process Heat Energy Consumption

Second Pattern Group*

Total Annual Btu's 2.43×10^{10}

Average Annual Btu's Per Plant 6.08×10^{9}

	Percent of total
1. Space heat	56.7
2. Process tank heating	15.7
3. Boiler losses	12.2
4. Rinse tank heating	5.8
5. Cleaner tank heating	5.2
6. Vapor degreaser heaters and stills	3.7
7. Ovens and dryers	.3
8. Other uses	.4
	100.0%

*Includes plants A, K, R and T

IV. OPPORTUNITIES FOR ENERGY SAVINGS IN PLATING AND SURFACE FINISHING

A. Exhaust Fans

The electric motors driving the fans that exhaust fumes from the plating baths are the single largest consumer of electrical energy. High ventilation requirements also contribute greatly to space heating and cooling costs. Thus, any substantial reduction in the number of air changes per hour will result in substantial heating and cooling cost savings.

There are several approaches to reducing ventilation requirements while continuing to maintain plant air quality standards.

1. Enclosing the entire plating line - Actually extending the walls of the tanks vertically and adding a horizontal cover above the hoists and support work is a very effective method for reducing ventilation requirements. This can perhaps be visualized as a scale-up of recent developments in strip plating where process, rinse and cleaner tanks are totally enclosed. Ventilation requirements are low. Fumes are exhausted through relatively small ducts connected to the top of each tank.

One plant that has successfully enclosed a complete barrel plating line has reduced exhaust fan energy consumption on this line by nearly 80%. The former ventilation system required a 25 hp fan motor, the present system utilizes a 5 hp fan motor. Further study on the feasibility of enclosing plating lines is now a part of this project. A subsequent report will be issued detailing findings.

2. High Efficiency hoods - Any new plant or plating line should be analyzed for the economics of high efficiency hoods. The first cost is higher but the result is lower exhaust fan power consumption and less air moved through the plant. The difference between high efficiency and standard hood design can be as much as 50% of the air volume moved. Replacement of existing

hoods is probably uneconomical in most cases.

3. More efficient fans - Fan efficiencies vary very widely. Replacement of existing fans may be economical in extreme cases. Any new installation should be questioned for fan efficiencies and the additional first cost (if any) for more efficient fans. Savings are dependent on the actual increase in efficiency.

4. Reduce the evaporation rates of tank fluids - Any permanent reduction in evaporation rates of tank fluids via ball blankets or lower operating temperatures, new baths etc. should be followed by an examination of the new exhaust requirements. A substantial reduction may be accommodated by installing a smaller motor on the existing belt driven fan with pulleys sized to lower the revolutions per minute of the fan and thus lower the amount of air moved.

5. Use of idler motors - Off production hours still require ventilation of certain area to prevent build-up of noxious fumes. When tank heating is turned off, as on a weekend, tank temperatures and evaporation rates fall as do ventilation requirements. A few survey plants had installed idler motors in parallel with the main drive motor. This smaller motor is used to drive the fan during off hours, typically resulting in 70-80% lowered electrical energy consumption during those periods.

B. Rectifiers

Most of the DC electric power used in the electroplating industry is supplied by rectifiers. These rectifiers change three-phase alternating current to direct current with a small amount of ripple. There are heating losses associated with the components of a rectifier. The overall efficiency varies, depending on the type of rectifier, silicon diode or selenium cell; the type of rectifier control; the rated output voltage; and the rated output amperage. Rectifier efficiencies range between 70% and 90%. The efficiency of a rectifier is very dependent on voltage. The efficiency increases with output voltage. Therefore, a rectifier should be operated near its rated output voltage. A rectifier operated at 50% of its design voltage will have losses that are approximately 30% higher than a rectifier designed to operate at that voltage. Rectifier efficiencies are less dependent on current. The efficiency is approximately constant from 50% to 100% of the maximum current rating. That is, the heating losses are proportional to the current from one-half to full load at a given voltage.[1]

Most selenium rectifier units experience a period of aging. During the first 5000 to 10,000 hours of operation, the rectifier efficiency decreases to a final value. Increasing the operating temperature accelerates the aging process. It should be noted that the rectifier cooling system should be sized for the heating loss at the final rectifier efficiency. Non-aging selenium rectifiers are now available.[2]

Energy can be saved by reducing unnecessary overplating. Automatic controls can maintain a constant voltage or current density. In addition, programmed controls are available. Also, devices employing an ampere-hour meter can be used to control the process.[3]

The maintenance requirements of rectifier units are slight and often neglected. The cooling system should always be in good operating condition. Usually, this means routine maintenance on the fan and motor and periodic cleaning of the inside of the air passages to remove dust and dirt which can impair cooling and increase corrosion. The coils on water cooled units should be kept free of water side scale. At the same time, the rectifier components can be checked for corrosion.[4] It is recommended that the rectifier efficiency be measured periodically. The manufacturer should be able to supply the details of this test. A volt-ohm-milliameter (VOM) is useful for performing tests on a rectifier. Reference 3 details methods using a VOM to approximate the ripple voltage and to check the rectifier ammeter. Clamp on ammeters are available to measure AC current without making physical connections. A cathode-ray oscilloscope can also be a useful diagnostic tool. The oscilloscope can be used to measure and compare AC voltage at various points in the rectifier and to observe the resulting ripple voltage. It is suggested that the ripple voltage pattern be observed and recorded while the rectifier is operating properly. This can then be used as a comparison should trouble develop.[5]

C. Stray Currents

In a normal plating operation the workpiece has negative potential. The current flows through the electrolyte between the anode and the workpiece. A stray current exists when the current path deviates from this. Stray currents can be separated into two classes. In the first type of stray current, the current path leaves the electrolyte at one point and re-enters it at another point. One point will act as an anode, the other as a cathode. Usually, this path is through the tank. The anodic point becomes a hole. The cathodic point plates up, and can lead to bridging from the tank to the nearest anode in the worst cases. In the second type of stray current, the current path is between the workpiece and ground, often wandering through the shop, accelerating corrosion.[6] References 7 and 8 describe a simple ground light system which can be used to detect this second type of stray current.

Today, plating tanks are either lined with a plastic or rubber material or are made of a non-conducting material. Stray currents are rarely a problem except in certain continuous, strip plating operations.[9] When stray currents do exist, the results are often noticeable. Plating quality suffers, the tank plates to the anode, or a hole appears in a tank. Given that these symptoms dictate a swift solution, it is unlikely that stray currents result in significant energy losses. Reference 10 also discusses methods of detecting stray currents.

D. Contact Resistance

There are many electrical connections and contacts in a plating shop. Each contact consumes energy in the form of I^2R heating losses. These losses can be minimized with proper design and maintenance of the contacts.

The resistance of contact results from constriction resistance, the constriction of the current flow to a smaller cross-sectional area, and from the resistance of thin films on the surface of the contacts. Constriction resistance exists because only a small portion of the apparent contact area is bearing any load. The current flows across the load bearing contact area. The load bearing contact area and, therefore, the contact resistance depends on the contact pressure. Various types of thin films can exist on the surface of a contact. They can be from several molecules thick down to a single layer of molecules. The films can consist of molecules from the atmosphere such as oxygen, compounds containing the metal such as oxides, or alien substances such as lubricant or water.[11]

Steps can be taken to keep the contact resistance low. Contact surfaces should be free of oxide and contaminants. In some cases, especially in preparing bus bar joints, joint compounds such as petrolatum, No-Ox-Id, Grade A Special, or Alco No. 2 Electrical Joint Compound are useful in preventing the reformation of oxides.[12,13] These compounds squeeze out of the joint leaving only a thin film which contributes no appreciable resistance. In addition adequate pressure must be applied to the contact. Platers maintain the contacts on the plating tanks fairly well.[14] These contacts are visible and accessible. Bus bar joints, however, are rarely maintained. There may be some energy savings to be had by cleaning and tightening bus bar joints. Measuring the voltage drop across any given contact will indicate the need for cleaning and/or maintenance. A temperature measurement would also indicate this need if the temperature of the contact is higher than that of the surrounding equipment. A pyrometer or an infrared scanner would be very useful in this regard.

E. Conductor Sizing

Heat is generated in current carrying electrical conductors. This heat loss is a potential source of energy savings. The energy loss is proportional to the product of the square of the current carried and the resistance of the conductor. This is normally referred to as I^2R losses. In the case of DC electrical conductors, the current is distributed uniformly over the cross-section of the conductor and the resistance is inversely proportional to the cross-sectional area. The operating current for a DC busbar is usually chosen to be the current required to achieve a certain specified temperature rise in the bar. The operating temperature is selected considering various mechanical properties such as strength, creep, thermal expansion, and fatigue life. The heating loss is not considered in most cases.

The heating loss can be reduced by reducing the current density in the conductor, i.e. the quantity of current flowing per unit area of conductor cross-section. This amounts to a trade-off between the initial cost of the conductor and the operating cost of electrical energy. An optimum design would minimize the sum of these costs over the life of the system.

The idea of optimizing the current density has been treated in the literature.[15,16,17,18] A slightly different approach to the problem is taken here. The method presented here, computes an optimum current level for a given busbar size and shape. A discussion of the technique follows. The economics of the problem are discussed first. An approximate method, using an empirical relationship generated by the Copper Development Association, is outlined. Laminated busbars are discussed. Finally, two example problems are given in Appendix C.

This problem is complicated by the complex relationships between current, resistance, cross-sectional area, cross-sectional shape, ambient conditions, and operating temperature. The approach taken here is to fix the conductor size and shape and to develop an approximate expression for the heating loss as a function of current using an empirical expression. The resulting function, L(I)(watts/linear foot of conductor), is used to compute the operating cost.

This objective is to minimize the cost per ampere delivered. That is, the total cost, T, divided by the number of amps carried. The total cost is made up of the initial cost of the busbar plus the cost of operating the busbar. C_i, the annualized initial cost, and C_o, the yearly operating cost, are computed as follows.

$$C_i\ (\$/\text{ft yr}) = W(\text{lb/ft}) \times p_m\ (\$/\text{lb}) \times f(\$/\text{yr}/\$) + \ell(\$/\text{ft}) \times f(\$/\text{yr}/\$)$$

where,

W = weight of the busbar (lb/ft)

p_m = price of the busbar material (\$/lb)

ℓ = cost of installation (\$/ft)

f = ratio of annual cost to first cost (\$/yr/\$)

$$f = \frac{1}{\sum_{n=1}^{N} \frac{1}{(1+k)^n}}$$

where,

N = payback period ÷ years

n = summation index

k = cost of capital, a ratio

$$C_o\ (\$/\text{ft yr}) = L(I)\ (\text{watts/ft}) \times \frac{1\ \text{kw}}{1000\ \text{watts}} \times H\left(\frac{\text{hr}}{\text{yr}}\right) \times p_e\ (\$/\text{kwhr}) \times \frac{1}{\eta}$$

where,

$L(I)$	=	approximate expression for heating energy loss as a function of current carried (watts/ft)
H	=	yearly hours of operation (hr/yr)
P_e	=	effective electric power rate (\$/kwhr)
η	=	rectifier effiency

Then,

$$T\ (\$/\text{ft yr}) = C_i(\$/\text{ft yr}) + C_o\ (\$/\text{ft yr}).$$

Alternatively, P_m can be replaced by $(P_m - P_s)$, where P_s is the salvage value of the bus bar discounted over the life of the system.

The quantity to be minimized is A, a type of average cost, (see Figure 1)

$$A(\$/\text{ft amp yr}) = T(\$/\text{ft yr}) \div I(\text{amp})$$

The optimum current, I_{opt}, is the value for which A is minimum, A_{min}. $A(I_{opt})$ is a minimum point if the two following conditions are satisfied.

$$\frac{dA}{dI}(I_{opt}) = 0, \quad \text{and} \quad \frac{d^2A}{dI^2}(I_{opt}) > 0.$$

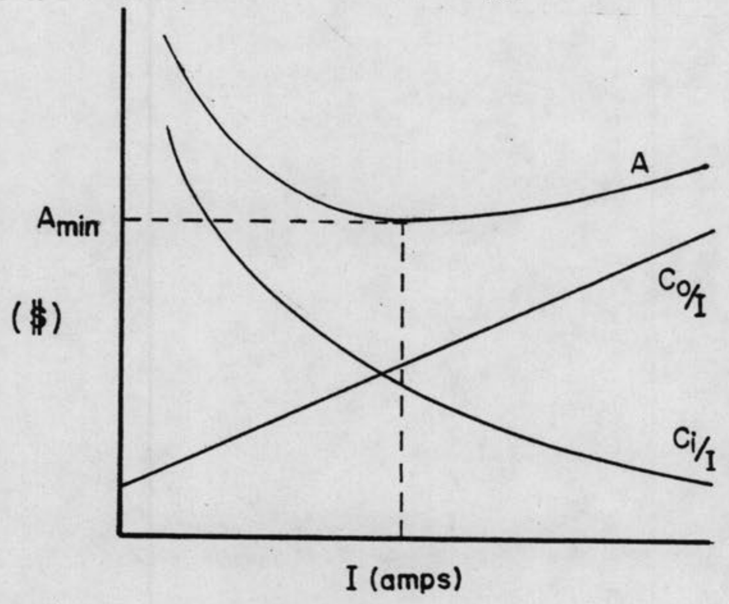


FIGURE I: BUS BAR CURRENT FOR MINIMUM LIFE-CYCLE COST

An expression is needed to approximate the heating loss as a function of current. The accuracy of the end result will depend upon the accuracy of this approximation. The Copper Development Association has developed an empirical expression to calculate the DC current that produces a given temperature rise.[19] The following expression is for normally tarnished, flat copper bars, mounted horizontally on edge in a draft-free atmosphere.

$$I = \frac{24.9 \times a^{0.5} \times p^{0.39} \times \theta^{0.61}}{\sqrt{(1 + \alpha\,\theta)\rho}} \quad \text{Amperes}$$

where,

I = current (amps)

a = cross-sectional area of the conductor (cm^2)

p = perimeter of the conductor (cm)

Θ = temperature rise (°C)

α = resistance temperature coefficient at ambient (1/°C)

ρ = resistivity of copper at ambient (microhm cm)

The heating loss associated with a given temperature rise, θ^*, and the corresponding current, I^*, can now be computed by calculating the resistance at the resulting temperature and multiplying by $(I^*)^2$.

$$L_1^* = \frac{(1 + \alpha\Theta^*)\rho}{a} (I^*)^2 \; \frac{30.48\text{cm}}{\text{ft}}$$

These points, L_1^* versus I^*, can be used to fit a curve, thus producing a simple, approximate functional relationship between heating loss and current. A least-squares curve fitting procedure can be used to generate the function $L_2(I)$ where $L_2(I^*) \simeq L_1^*$ and is of the form

$L(I) = a_1 I + a_2 I^2$, where a_1, a_2 are constants.

The economic analysis can now be completed. The functional form of A is as follows:

$$A = \frac{C_i}{I} + ga_1 + ga_2 I,$$

where,

$$g\,(\$/\text{yr watt}) = \frac{Hp_e}{1000\eta}. \quad \text{Find } I_{opt} \text{ such that } \frac{dA}{dI}(I_{opt}) = 0.$$

If $\frac{dA}{dI} = \frac{C_i}{I^2} + ga_2 = 0$, then $\left[\frac{(C_i)}{ga_2}\right]^{1/2} = I.$

The final expression is as follows:

$$\left[\frac{Wp_m f + \ell f}{a_2 \frac{1}{1000} Hp_e \frac{1}{\eta}}\right]^{1/2} \text{ (amps)} = I_{opt} \text{ (amps)}$$

The second order condition, $\frac{d^2A}{d\,I^2} > 0$, is always satisfied since

$$\frac{d^2A}{d\,I^2} = 2\,\frac{C_i}{I^3} > 0 \text{ for } C_i > 0 \text{ and } I > 0.$$

The publication, Copper for Busbars indicates that the loss of current carrying capacity for the first additional bar in a laminated bus bar system is on the order of 16% when the bars are on the order of 1/4" thick and spaced one bar thickness apart. This means, at a given temperature, two bars carry approximately 1.84 times as much current as one bar. For each additional bar, the current carrying capacity is reduced by approximately 32%. So, M bars, $M > 2$, each rated at I_1, for a given temperature rise, will carry I_m,

$$I_m = [1 + 0.84 + 0.68 \times (m-2)] \times I_1 .$$

Define a current reduction factor M, as follows:

$$M_m = 1.84 + 0.68 \times (m-2) \text{ for } m > 2,$$

$$M_2 = 0.92,$$

$$M_1 = 1 \quad .$$

The point computed from the CDA empirical formula can be used to determine the current in a laminated bar system at a given operating temperature.

$$I_m = MI_1, \; L_m = I_m^2 \; R = M^2 \; I_1^2 \; R$$

These new points can be used to generate another least squares fit curve. The same expression is then used to compute I_{opt}.

Two example problems appear in Appendix C. The price of copper is taken to be $1.32/lb. The price of electricity is taken to be 3¢/kwhr. The desired payback is 3 years at 10%. For a single 1/4" x 4" bar, the optimum current is found to be 1136 amperes. For 3 laminated 1/4" x 4" bars, the optimum current is found to be 1050 amperes per bar.

These results are only as accurate as the representations for L(I). Ideally experimental results would be used to obtain an empirical expression for each bar size and grouping. Also, expressions would be developed for aluminum bus bars.

F. Lighting

Lighting accounts for 10-15% of the energy usage in an electroplating plant. The typical plating shop uses sodium vapor on metal halide lighting at the ceiling level in a high bay room with flourescent lighting at the work level. The potential for energy savings is not as large as it is in other areas of energy consumption. However, significant percentagewise energy usage reductions can be achieved. The actual amount will depend on existing lighting levels and luminaire types. Lighting energy consumption can be reduced in one of several ways. 1) Lighting levels can be reduced. 2) Lights can be operated for shorter periods of time. 3) Existing lighting equipment can be replaced with more efficient types.

Certain areas of a plant may receive more light than is actually necessary for the tasks being performed. However, worker safety, productivity, morale, and comfort must be carefully considered before reducing existing lighting levels. In some cases, general lighting levels can be reduced while additional lighting is provided at work stations. The Illuminating Engineering Society (IES) provides guidelines for ratios of task light to surrounding light.

In reducing lighting levels, luminaries can be disconnected or removed, lamps can be removed from the luminaires, or existing lamps can be replaced with lower wattage lamps. It should be noted that removing the lamp from a ballast-type luminaire does not cut its energy usage to zero. The ballast will still consume as much as 20% of the total energy used. The luminaire must be disconnected to achieve 100% energy savings. It is advisable to remove the lamps, evaluate the new lighting levels, then, if the new lighting levels are acceptable, disconnect the luminaire.

Lighting needs can actually be reduced. It may be possible to schedule work to reduce the lighting requirements at any given time. Lights could be turned off in areas of the plant that are not in use. Increasing the reflectance of plant surfaces such as ceilings, walls, and floors will reduce the amount of light needed to provide a given lighting level. The IES recommends reflectances of 80% for ceilings, 50% for walls, and 20% for floors.[20]

Lighting energy consumption can be reduced while lighting levels remain constant or increase, through the use of more efficient lighting systems. In some cases, efficiency improvements can be obtained by changing lamps. Several manufacturers market reduced wattage fluorescent lamps with higher efficiencies. Calculations in Appendix D compare the energy savings of energy saving flourescent lamps to their additional initial cost. At least one manufacturer is marketing an energy saving ballast. They claim up to 47% reduction of ballast energy losses with a much longer ballast life. When used with energy saving lamps, the ballast is claimed to reduce fixture wattage by an average of 19%. Even when used with standard lamps, the ballast is claimed to reduce fixture wattage by an average of 5%. Westinghouse Electric Corporation has developed a 300 watt metal halide lamp that will work in most luminaires designed for 400 watt mercury vapor lamps.[21] The metal halide lamp produces over 50 percent more light than the mercury vapor lamp with better color rendition. It may be more desirable to use a different type of luminaire for a more efficient lighting system. Among the factors affecting the choice are the following:

1. Lamp efficacy (light output per power input)
2. Lamp life
3. Lamp cost
4. Lamp color characteristics

5. Luminaire spacing
6. Luminaire cost
7. Luminaire maintenance requirements

Table 7 compares the efficiency and life of various types of lamps.

TABLE 7
TYPICAL LAMP EFFICACIES AND LIFE RATINGS*

Lamp Type	Efficacy, lumens/watt Low	Average	High	Average Life, hr
Incandescent (general service)	10	16	23	750
Incandescent (extended service)	9	13	17	2,500
Fluorescent (standard output)	51	75	91	20,000
Fluorescent (reduced wattage)	58	73	83	20,000
Mercury (reflector type)	25	37	49	24,000
Mercury (standard)	42	54	63	24,000
Metal halide	80	100	125	10,000-15,000
High-pressure sodium	95	119	140	24,000
Low-pressure sodium	131	151	183	24,000

*Actual ratings for specific lamps can be obtained from lamp manufacturers.[22]

Also available is a feedback system that controls the light output from flourescent luminaire by controlling the power input.[23] The controller is adjusted for the desired light output. It maintains the level of light output over the life of the lamp by gradually increasing the power input to counteract the degradation of the lamp. Designed overlighting is not necessary to insure adequate lighting near the end of the bulb life. The company claims as much as 15% savings in average power usage. Additional savings are gained where natural lighting is available. The system reduces the light output in areas where daylight supplements plant lighting.

A systematic approach should be used in upgrading a lighting system to guarantee a satisfactory end result. The procedure should begin with a survey of the plant and outdoor surroundings. A planview of plant and a site plan are useful for this. Luminaire types, wattages, locations, and hours of operation should be determined. In addition, existing lighting levels should be noted. Areas where lighting levels can be reduced should be noted. Information must be collected on available lighting alternatives. The electric-billing-rate structure must be analyzed to determine the effective cost of energy. The information from the plant survey along with the information on alternatives must be analyzed to establish energy saving possibilities. A simple, economic analysis must then be done to determine the feasibility of each proposed change. Priorities should be established. Work can then begin on any desired changes. In addition, a maintenance plan should be established. A well maintained system can provide a given lighting level for less energy.[24,25,26]

Almost all of the energy input for indoor lighting ends up as heat. This heat supplements the heating system during the winter months and provides an additional load for the air conditioning system during the summer months. The effects of lighting system changes on the space conditioning requirements need to be considered. Most of the survey plants did not have air conditioning. Any reduction in lighting energy input would result in increased heating requirements. Only a portion of the direct savings would be realized. Some plants do have air conditioning systems. Printed circuit board plants, which maintain a controlled environment, use large amounts of energy for air conditioning. Reducing the lighting energy input can save cooling energy in addition to the direct savings on lighting. The amount of indirect energy savings which can be obtained will depend on the air conditioning and ventilating system.

G. Utility Rates

The leading motivation for energy conservation is reduced operating costs, largely in the form of lower fuel and utility bills. Electric power bills can be reduced in other ways in addition to energy usage reduction. These possibilities should be investigated.

A number of factors affect the amount of the electric power bill. One important factor is the rate schedule. Usually, more than one rate schedule are applicable to a plant. Often, as many as six or more options are available. And, special contracts can sometimes be negotiated. It is the customer's responsibility to determine and obtain the most favorable rate schedule.[27] The voltage and location of the service affect the power rate.

Most industrial rate structures include a peak demand charge. The details of this charge should be understood. Typically a plant is billed for the highest demand in any given fifteen minute period during a given month. A new demand charge is figured for the following month. Procedural changes can lead to reduced peak demand charges. Systems are available to continuously monitor demand and automatically shed loads to keep the demand below an assigned value.

Many industrial rate structures include a power factor charge. The power factor is the ratio of true power in kilowatts to apparent power in kilovolt-amperes. The power factor ranges between zero and one. In plants having a low power factor, much of the current drawn does no work. The power company must have equipment to handle this added current, yet receives no income from it. Induction motors, certain saturable reactor rectifier controls, and certain types of ballast lighting have low power factors. Power factor correction, largely in the form of static capacitors across the line, is available. The details of the power factor charge should be examined and an analysis done to determine the amount of power factor correction that is economically justified.

H. The Economics Of Air Agitation: Blowers vs. Compressors

Air agitation is used in certain plating, anodizing, cleaning and rinse baths in the plating industry. Its uses are quite varied and depend, to a large extend, on the preference of the individual plater. Nickel, and copper plating baths are the most frequently air agitated plating baths. Air agitation is widely used in production plating plants. Rule-of-thumb methods are used to specify the amount of air to be supplied to a tank. Generally, the volume flow rate of air is based on the surface area of the tank. It ranges between 1 and 4 cfm/ft^2 of tank surface area. Rinses are usually agitated gently. Plating baths using air agitation are usually agitated vigorously.[28,29]

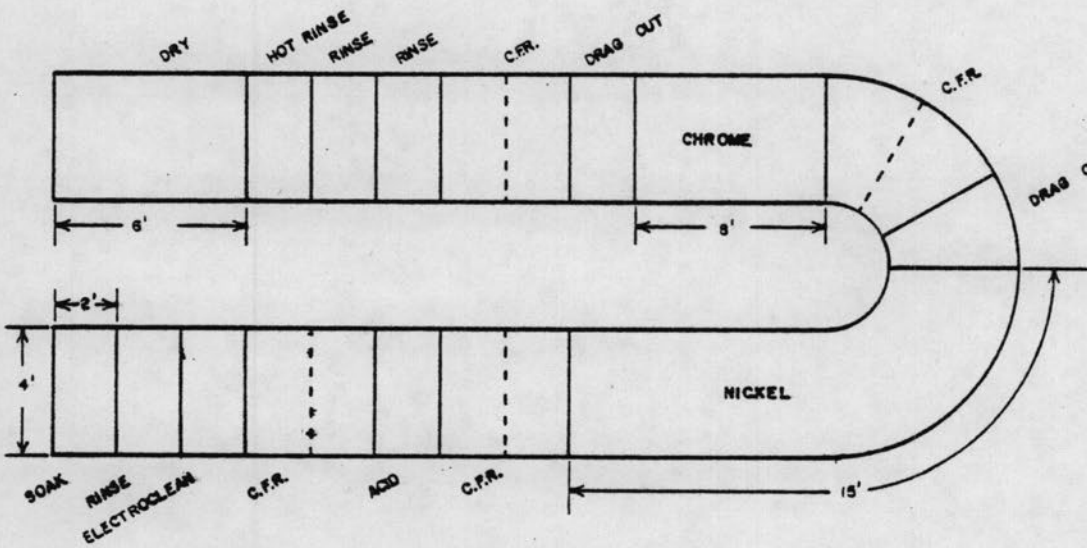
Over twenty-five percent of the survey plants use compressed air for air agitation. The air is supplied by air compressors which provide air, typically at 80 psig, for other plant services. In some cases, compressed air requirements have been reduced until air agitation is the only use for the compressor. Plants in this position would be well advised to replace their compressors with blowers in the event of major repairs.

Virtually all new plating lines that use air agitation are equipped with blowers. A study has been made to determine the economic feasibility of installing a new blower to replace compressed air on an existing plating line. The calculations appear in Appendix E.

A rack-type, nickel-chrome plating line was chosen for the analysis (see Figure 2). The line is four feet wide and four feet deep. The nickel tank is 15 feet long, the chromium tank is 8 feet long, and the remaining tanks are 2 feet long. The nickel tanks are agitated at a rate of 1.5 cfm/ft^2 of surface area. Twelve rinse tanks are agitated at a rate of 1.5 cfm/ft^2 of surface area. The plating line requires 235 cfm at 2.7 psig. A blower was sized to supply this requirement. Initial cost and power requirement were determined. It is assumed that air is presently supplied by a large plant compressor. The power requirement was determined for a reciprocating air compressor with a capacity of 800 cfm at 80 psig. This information was used to figure the rate of energy use in kwhr/ft^3 of air at 2.7 psig for the blower and the air compressor. The rates for the blower and air compressor are; 1) 3.6×10^{-4} kwhr/ft^3 @ 2.7 psig and 2) 4.70×10^{-4} kwhr/ft^3 @ 2.7 psig, respectively. The difference is used to determine the annual energy savings potential.

The annual savings, in dollars, has been calculated for 1,2, and 3 shift operation, five days a week at 3, 4, and 5 ¢/kwhr. The annual savings is then compared to the annualized cost of the capital investment. For the case of three shifts per day, five days per week, with electricity at 5¢ kwhr, the yearly savings is $480. The installed cost of the blower is approximately $2923. For a desired rate-of-return of 10% with a three year payback, the annualized cost is $1175. The maintenance cost is estimated to be $100 per year. This results in a net equivalent annual worth of -$795. For this set of assumptions, the blower is not a good investment.

For this example, the purchase of a blower is not economically feasible. However, this result is very sensitive to the assumptions. Situations can exist where it is economically feasible to purchase a blower. A less efficient air compressor will increase the rate of energy use and increase the potential savings. Higher electric rates will also increase the potential savings. Higher flow rate requirments will allow the use of higher output blowers, possibly reducing the capital dollars per cubic foot per minute of capacity. Corporate income taxes will also affect the decision. Taxes were not included here due to the wide varience in tax rates. Taxes will play a major role in the decision. A simplified treatment of corporate income taxes is given in Appendix E.



NOTE :
C.F.R. = COUNTER FLOW RINSE

FIGURE 2: TYPICAL NICKEL-CHROME PLATING LINE

I. Tank Heating

Heating of the plating baths, rinses and cleaners is the largest consumer of heat energy totaling 45.1% overall. Electrical energy is also consumed in this function. Substantially reducing the energy consumed in this area is difficult. Several things, however, can be done to save energy.

1. Lowered temperatures - the best answer to the challenge is to develop lower temperature plating baths and cleaners. Several of the chemical supply companies are working in this direction and hopefully will continue to do so.

2. Tank insulation - unfortunately this may not be a very good answer to the problem. The majority of heat lost from a hot tank is due to evaporation not convection from the tank walls. Additionally, conventional insulation will deteriorate rapidly in this service thus negating any savings. Plating solutions or hot rinse water can soak the insulation rendering it ineffective and hastening its demise. This implies that a cheap durable, effective, water/solution proof covering is needed. A double wall tank can be built with insulation between the walls. The tremendous additional expense is not, however, justified by the savings available.

Table 8

Approximate Percentage Heat Loss Evaporation and Convection for Various Temperatures*

Tank Size	Tank Temp. °F	Heat Loss Btu/hr	Evaporative	Convective
3.8' x 4.7' x 4'	120	27,700	72%	28%
5.3' x 3' x 4'	150	54,900	76%	24%
10.5' x 4' x 4'	180	294,000	87%	13%
5' x 3' x 4'	200	105,000	83%	17%

* Calculated for various tanks in the twenty survey plants

Properly insulating a tank will reduce the heat loss as much as 90%. For the above four tanks this amounts to approximately 69,000 Btu/hr saved. Based on two shifts per day, five days per week this amounts to about 2.8×10^8 Btu/yr or about \$690/yr saved in fuel costs (this assumes the cost of gas at \$2.00 per MCF and a boiler efficiency of 80%). The cost to double wall and insulate existing tanks is at least \$500 to \$700 each, thus the return on the investment is not very attractive.

A few of the plants in the survey have recently insulated one or two select tanks without installing protective measures. The payback is good so long as the insulation is not destroyed in service, which is exactly what these plants are attempting to evaluate.

3. Ball blankets, tank covers - plastic ball blankets are a very effective tool for lowering evaporation losses. They are not however, useful in all applications. Automatic lines in particular are not good candidates for their use as they tend to nest in the work. Hand lines are much better suited for ball blankets. With some care they can be successfully employed. Manufacturers claim reduction of 70 to 80% in evaporation losses. Survey plants using ball blankets substantiate these claims.

When ball blankets are not practical, a removable tank cover may be useful during lunch breaks, between shifts etc. A few of the plants surveyed used sheet metal or plywood covers to reduce evaporation losses.

4. Equipment maintenance - the heat exchangers used to transfer heat from steam to the tank fluid need to be kept free of scale to minimize energy usage. Temperature controllers must also be kept in proper operating condition for the same reason.

J. Plating Baths

The amount of energy required to plate out a specific amount of metal depends on a number of operating conditions such as the cathode efficiency, the metal ion present in the bath, the voltage requirement, the heating requirement, and the plating speed. These factors are interrelated and depend on the type of plating bath. The metal ion present is determined by the type of bath. The cathode efficiency depends on a number of factors, but usually can be controlled to vary over a small range for a given type of bath. The bath type and composition are selected to achieve a quality plating as rapidly as is possible, based on the part material and shape. Historically, energy requirements are not a consideration.

Plating bath suppliers are beginning to look at the energy requirements of plating baths, especially temperature requirements. Efforts are directed to reducing the temperature of high temperature baths as well as increasing the temperature tolerance of low temperature baths, which often have cooling requirements. For example, low temperature nickel baths are now on the market. They operate at 95°-110°F as opposed to 135-150°F for conventional nickel baths. These baths are less expensive to operate due to reduced energy usage and reduced chemical costs. Also, acid zinc baths, which can, in many cases, be substituted for cyanide zinc baths, use from 1/3 to 1/2 less electrical energy. There is, however, an associated increase in chemical costs.[30,31]

Plating baths must be chosen to insure product quality. However, the energy requirement need not be totally ignored. Plating bath suppliers should be consulted to determine where opportunities exist to reduce energy consumption without sacrificing plating quality or speed.

K. Alkali Cleaning

A very clean surface is required to produce a quality electroplated deposit. The amount and type of cleaning required for a part will depend on the part material, finish, and the operations preceding cleaning. Cutting oils, lubricants, buffing compounds, corrosion inhibitors, and other soils must be removed. Much of this cleaning is done in energy intensive, high temperature soak tanks using an alkali cleaner. Therein exists a large potential for energy and monetary savings. Cleaning costs can be reduced by making the parts easier to clean. This can be done by modifying the preceding operations, changing the types of lubricants and oils used, reducing the use of buffing compounds, and shortening the inventory time.[32] Lower temperature cleaners can be used. Cleaner manufacturers are placing a major emphasis on producing low and ambient temperature alkali cleaners. There are now on the market low temperature alkali cleaners which are effective on most soils with the exception of buffing compounds based on high-melt waxes and fats. One manufacturer has been testing an alkali cleaner in 32 plants, at temperatures ranging from ambient to 110°F, with very good results.[33] Alkali cleaner suppliers should be consulted about the applications of new low temperature cleaners.

L. Rinsing

Rinsing is the least energy intensive of the three catagories of tank heating. Energy savings are available through several techniques.

1. Cascade rinsing - counter-flow rinses are a relatively well known way to effectively rinse with less water and energy. Substantial savings can be achieved using two rinses in counter-flow versus two single rinses in series.

2. Input flow control - limiting the water input to a minimum will reduce energy usage. Several plants utilize conductivity meters to measure contamination levels in any given rinse tank. Thus water is added only as needed. For rinsing situations where the work load is relatively steady, a flow-limiting valve may be useful and is less expensive.

3. Spray, fog rinses - the mechanical action of a spray rinse will often allow lower operating temperatures than for a stagnant rinse. Spray rinsing is commonly employed. One survey plant has recently installed a fog rinse station, which atomizes water around the work involved. Pumping energy usage is expected to be lower than for a comparable spray rinse and heating costs are expected to be lower than for a stagnant rinse to perform the same duty.

M. Boiler Operations

The typical plating plant boiler is a relatively small unit ranging in size from 30 to 200 horsepower. The most common size in the twenty survey plants is 125 horsepower. Stack gas analysis for several of these units show they range in efficiency from 76 to 78%. The great majority of available energy saving devices are simply not economical in this size range. This includes economizers, automatic blowdown controls and blowdown heat exchangers, and continuous excess oxygen monitoring. Captive plants with boilers in the 500 horsepower range and greater should investigate the economics of these items.[34]

In lieu of new capital equipment to make a boiler more efficient, the typical plating plant needs to maintain the plant boiler in top condition to insure maximum possible efficiency. This should include:

1. Periodic adjustment of the air to fuel ratio - This is best done twice a year, in early spring and late fall, to correct for changes in air density with changing weather conditions.

2. Water and fire side inspection and clean out - This should be done at least once a year to improve efficiency lost to the increased resistance to heat transfer caused by the build up of scale. Increased stack gas temperatures can be an indication of boiler scale.

3. Boiler water treatment - All plants with boilers have a system for softening or otherwise treating boiler water. Not all plants followed these programs as well as possible. This has led to lower boiler efficiencies in some cases and is avoidable. The well maintained boilers showed efficiencies 1-3% higher than those that were not.

4. Condensate Return - One area where virtually all platers can save energy is in returning condensate from heat exchangers in plating baths, cleaners and rinse tanks. Presently, steam condensate is discharged as plant waste water. Plating bath heat exchange elements will occasionally develop leaks, condensate will then become contaminated with the acids and other chemicals present in the plating solutions. The results of returning contaminated condensate can be disastrous. In addition to the acute problems of foaming and priming, acid attack can accelerate boiler tube and casing failure.

It appears possible to apply available technology to solve this problem (see Figure 3). Monitoring condensate in a receiving tank for conductivity can provide an accurate means to prevent acid contamination from reaching the boiler. The probe signal would be interpreted by a transmitter - controller station which would activate a three-way solenoid operated valve in the condensate return line. Contaminated condensate would be discharged and an alarm could be used to alert plant personnel to the problem. One survey plant employs just such a system. It is important to check conductivity meters regularly and to maintain the other parts of the system to avoid failure.

Installation of a condensate return system shows a savings potential of 11.5% of the total boiler Btu input for a plant utilizing 15 psig steam, a common operating pressure. Using data from the plants surveyed this equates to 9.7% of all fuel consumed.

<u>Calculation of Savings Potential for Returning Condensate</u>

Fuel input to boiler:	22,000 MCF/yr
Stack loss is approximately	5,000 MCF/yr
Fuel input to water:	16,000 MCF/yr

$$(16{,}500\ \mathrm{MCF/yr})\ (1027\ \mathrm{Btu/ft^3})\ (1000\ \mathrm{ft^3/MCF})$$

$$\div\ (1164-28\ \mathrm{Btu/lb})\ =\ 1.5 \times 10^7\ \mathrm{lbs.\ stm/yr}$$

When condensed as liquid water and returned to the boiler at 200°F this represents:

$$(1.5 \times 10^7\ \mathrm{lbs/yr})\ (168-28\ \mathrm{Btu/lb})\ =\ 2.1 \times 10^9\ \mathrm{Btu/yr}$$

Since this heat is contained in the boiler feed water, and since the boiler combustion efficiency is about 80% the actual savings is:

$$2.1 \times 10^9\ \mathrm{Btu/yr}\ \div\ .8\ =\ 2.6 \times 10^9\ \mathrm{Btu/yr}$$

or 11.5% of the boiler input.

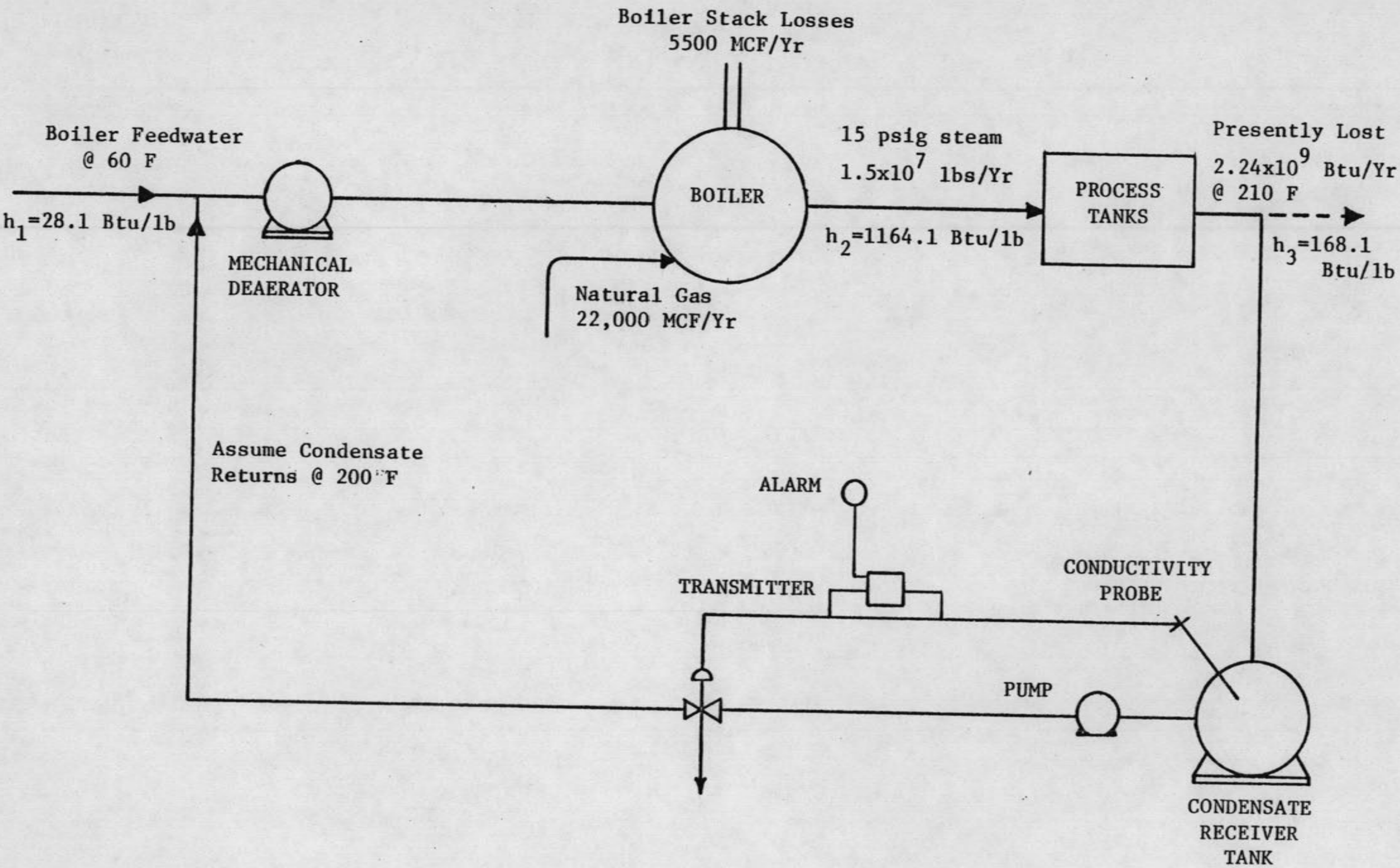


Figure 3. Condensate Return System

N. Pipe Insulation

Low pressure steam is commonly used in plating shops for heating plating tanks, cleaning tanks, dryers, and vapor degreasers. In many of the survey plants, the lines supplying this steam were found to be uninsulated. Often the pipes had been insulated initially, but the insulation had not been maintained. Bare steam pipe offers a potential for energy savings and cost reduction. Table 9 shows the potential energy savings for a given case.

The savings shown in Table 9 are based on using insulation of a certain economic thickness. Computer programs have been developed to determine the insulation thickness that results in the minimum cost over the life of the system (see Figure 4).

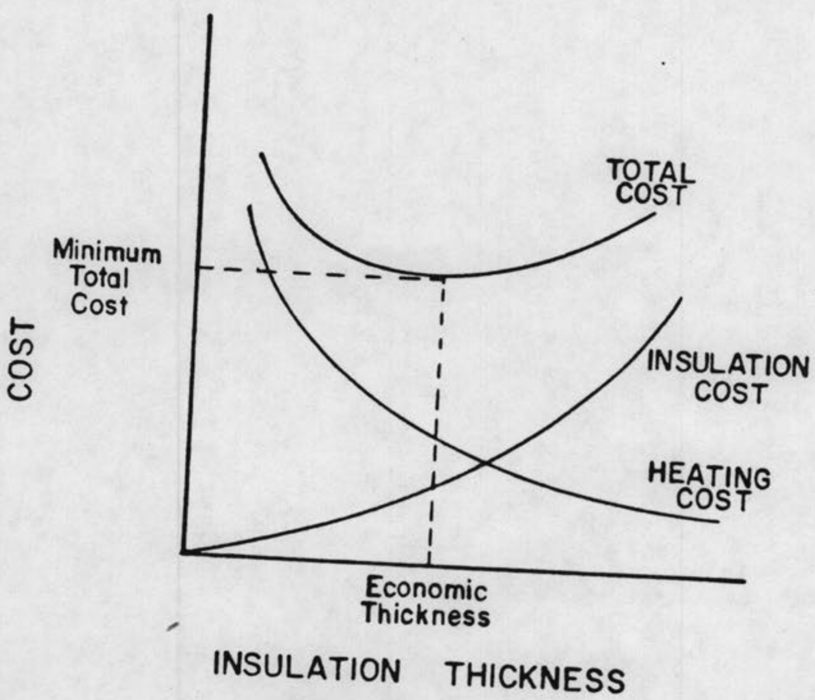


FIGURE 4

The programs take the following factors into account.

1) heat plant investment cost
2) depreciation period
3) heat cost increase rate
4) usage rate
5) installed insulation costs
6) insulation depreciation period
7) insulation maintainence cost
8) interest rate
9) income tax rate

Several insulation manufacturers have computing facilities available to run a program to determine the economic thickness for their customers, using the customer's assumptions of cost and economic conditions. In addition, the Thermal Insulation Manufacturers Association publishes two manuals for arriving at the economic insulation thickness.[37] One deals with new construction applications. The other deals with retrofit installations, including up-grading existing insulation. These manuals contain computer-derived tables giving the economic thickness for different cases.

The information and assumptions in Table 9 can be used to calculate the savings potential for a hypothetical plant. For a plant with 60 feet of 1", 30 feet of 2", and 20 feet of 3" uninsulated steam pipe, there is a savings potential of 7.9 X 10^7 BTU/year using the economic insulation thickness. This amounts to a monetary savings of $350 per year at the midlife cost of steam of $4.44/1000 lb. Plating plants typically use steam at 15 psig, 250° F. Therefore, the energy savings potential in this example is conservative, since it is based on a pipe surface temperature of 200° F. The resulting economic thickness and consequently the actual savings potential will depend on the individuals' assumptions and actual plant costs. The assumptions may be very different for insulating existing equipment as opposed to insulating new facilities. Installation costs are likely to be different. Also, the economic life may be shorter.

TABLE 9

Assumptions

Annual Fuel Price Increase 4%

Initial Heat Cost $3.00/1000 lb steam

Heat Cost at Midlife $4.44/1000 lb steam

Cost of Money 7.5%/year

Pipe Surface Temperature 200° F

Capital Investment $20/lb/hr Steam

Installed Pipe Cost (1½" x 1") $2.40/lf

Depreciation Period 20 years

Hours of Operation 5400 hr/yr

Ambient Temperature 80° F

Nominal Pipe Size (in)	Outside O.D. (in)	Economic[38] Thickness of Fiberglass Insulation (in)	Insulated[38] Heat Loss Btu/hr ft	Bare Pipe Heat Loss BTU/hr ft	Potential Energy Savings BTU/hr ft
1	1.315	1	15	103	88
2	2.375	1½	18	177	159
3	3.500	1½	23	255	232
4	4.500	2	23	320	297

Certain types of insulation are available with a plastic vapor barrier covering. This protects the insulation and is important in reducing both pipe and insulation maintenance. Most often, steam pipe was found to be uninsulated in the survey plants because the insulation had not been protected from the plant environment and as a result had deteriorated.

O. Ovens and Dryers

Ovens and dryers consume 7.0% of the process heat energy with electrically heated stress relief ovens using 4.5% of the electrical energy consumed. Typically, in a plant with several of these units, they are located at various points throughout the plant. Thus, ducting the exhaust together for heat recovery purposes is impractical. Individual units each consume relatively small amounts of energy, and ovens sometimes operate intermittently. Many of the gas fired units, however, offer the possibility of energy savings.

1. Many of the gas fired ovens and dryers are single pass units. Thus their overall efficiency can be improved drastically by recycling some portion of the exhaust air. This potential is greatest for dryers, some of which incorporate this feature (usually steam fed units) and probably lowest for ovens which operate closer to stoichiometric conditions. For a gas fired dryer operating at 250°F, recycling 50% of the exhaust air at 175° will result in a 30% reduction in fuel consumed.

Units which can measure the explosive limits of hydrocarbon-air mixture are now available for use in paint oven applications. These units can be employed to reduce energy usage in this important area.[35]

2. A simple mechanism for using oven and dryer waste heat would employ the exhaust gases as a supplement to building heat during winter months. This rules out paint ovens and any others which volatilize toxic or noxious fumes. A three way valve could be installed in the exhaust duct to route hot exhaust into the plant when desirable.

P. Space Heating and Cooling

One of the most effective ways to reduce plant heating and cooling is to reduce the number of plant air changes per hour, as previously discussed. Other approaches can also be used.

1. Use of infrared heaters - infrared space heaters are best suited to stagnant or near stagnant air conditions as in a warehouse operation. Several of the survey plants, however, use infrared heaters successfully to reduce heating costs. One plant uses gas infrared heaters as the only source of plant heat with approximately 50% less energy use than their previous direct fired heating system. Savings of 30% and more are typical.[36]

2. Isolate plating - this pertains to captive shops where there is no need to remove plant air from non-plating areas. For new plants, plating lines should be placed in a separate room or even a separate building to substantially reduce heating and cooling costs for other plant functions.

Q. Operational Procedures

Every plant visited had some piece of equipment running empty, doing no useful work. Almost every plant visited had one or more heated tanks operating at a temperature above the recommended temperature. More than one plant had all its lights on all of Sunday, a day when the plant was vacant. These items are perhaps best remedied by re-educating the personnel involved and perhaps with a little emphasis by management.

The survey plants provide several examples of this type of energy waste. In one plant, a shaker separating polishing media from the work ran empty 50% of the time. It was driven by a 5 hp motor. According to one of the plant's professional employees, a material sensing mechanism, such as an arm, and a switch would remedy the problem. The annual savings available are about $225 per year. Another plant operated two heated tanks 10° and 15°F above their normal operating temperatures of 150° and 135°F respectively. Better control of these tank temperatures would save about $160 per year. Turning off the lights on Sunday in another plant would save $2500 per year. This particular plant has approximately one quarter of a million square feet of floor area.

R. Sources Of Waste Heat And Possible Uses

Water, often softened water, is used to cool several types of equipment in the plating industry. These include:

1. Chillers
2. Vapor degreasers
3. Rectifiers
4. Evaporators
5. Air compressors

Sometimes this water is pumped to a cooling tower for reuse and sometimes it is discarded at temperatures in the 85° to 100°F range. This low grade heat may be suitable for reuse in several areas including:

1. Boiler feed water
2. Ambient rinse make-up
3. Hot rinse make-up
4. Process and cleaner tank make-up
5. Plant clean-up

Often it is very easy to pipe otherwise wasted water into a nearby tank. The majority of the above items, however, may not be in close proximity. Balancing available heat with areas for use can lead to satisfactory methods for collecting and distributing waste heat. At least one of the survey plants completed a program to reduce water and energy consumption with very satisfactory results.

S. Oversized Equipment

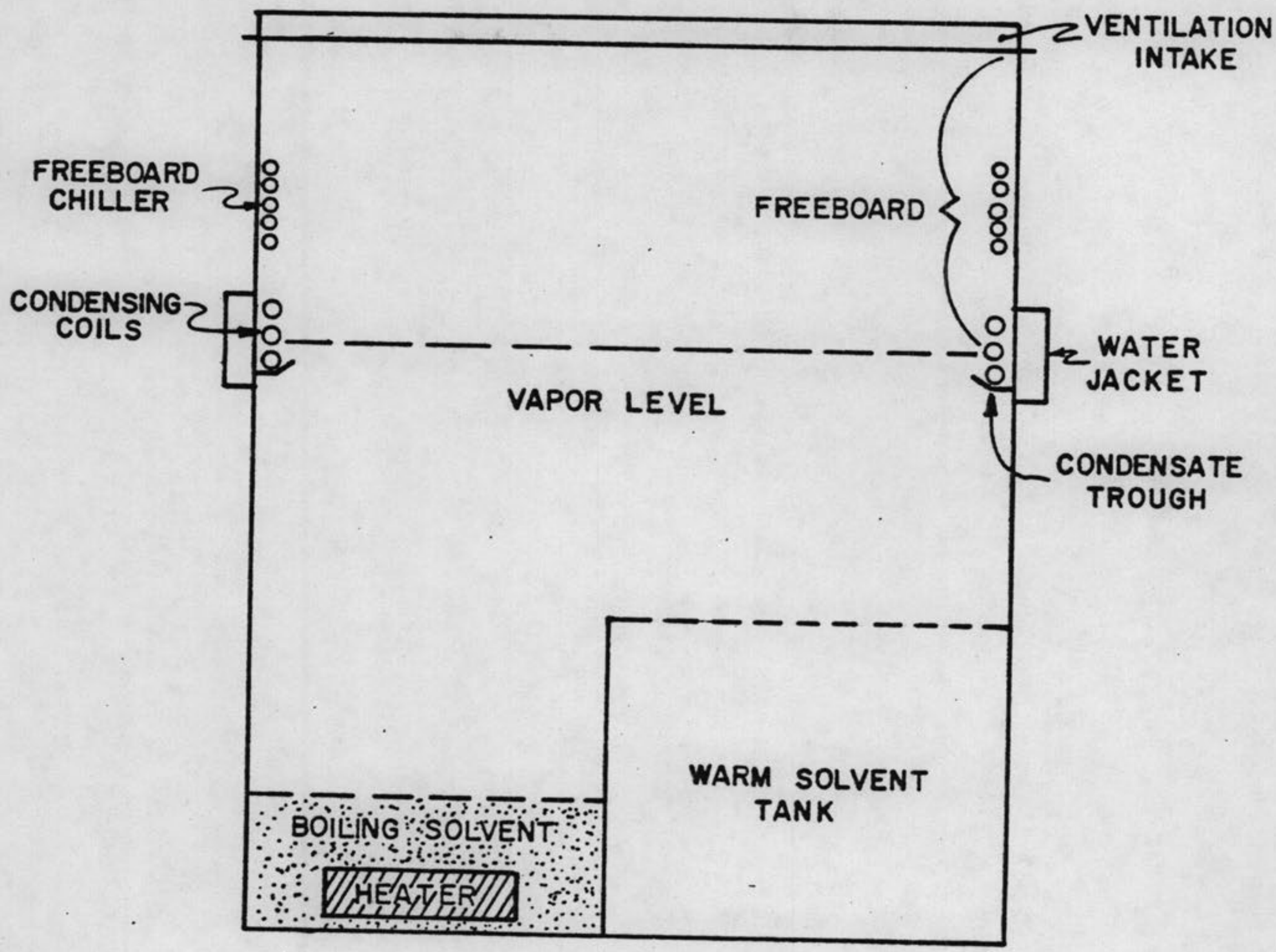
Often, requirements in a plant will change, such as for compressed air. Two of the plants visited had lowered their needs for compressed air but continued to operate their now oversized compressors. In one case 73% of the electricity consumed was used while idling. Although immediate replacement of the unit may not be economically attractive, the need for major repair on the unit should initiate a replacement of the proper size.

T. Vapor Degreasing

Vapor degreasing is a solvent cleaning method. The work piece is immersed in a tank of solvent vapor. The vapor condenses on the work, dissolving and carrying away oil, grease, and insolubles, until the work reaches the vapor temperature. Variations on the process include boiling solvent immersion, warm solvent immersion, and solvent spraying. All cleaning cycles end with a vapor rinse, so the emerging work is dry. The degreasers use chlorinated solvents and flourocarbon solvents. These solvents are nonflammable and have vapor densities which are greater than that of air. The open-top degreaser shown in Figure 5 is used as a batch operation. It can be used manually or with a mechanical lift. More and more continuous, conveyorized vapor degreasers are being sold.[39] These degreasers can be more economical through reduced labor costs and increased control of operating conditions. Vapor degreasing has long been used in the electroplating industry, though in recent years, its use has been on the decline.

Some vapor degreasers, especially the ones using higher boiling point solvents, are insulated. The insulation usually consists of between 1 and 2 inches of fiberglass batt covered by thin gauge steel sheet. In all cases, the insulation is provided for worker safety and comfort. Energy conservation has not been a consideration.[40,41] In fact, energy usage reduction is not possible on most existing machines.[42] The degreasers are either on or off. The heat input is constant while the machine is on. Insulating these machines will decrease the heat loss to the atmosphere while increasing the recycling of solvent and thereby increasing the load on the condensing system. Some newer degreasers have an idling feature which reduces the heat input when the degreaser is not in use. Usually these degreasers have two heating elements. The controls automatically close the cover and turn off one heater when the machine is idling. One innovation in vapor degresers employs a heat pump. It uses the refrigeration unit to condense the solvent vapor while using the heat from the refrigeration condenser to boil the solvent. This unit is becoming popular with the lower boiling point fluorocarbon solvents. One manufacturer claims an energy usage reduction of 60% over a conventional, electrically heated vapor degreaser for low boiling point solvents.[43] They can be used with the higher boiling point solvents, but the economic feasibility depends on the shop conditions and shop requirements.[44]

It appears that energy saving vapor degreasers will, in most cases, have to be supplied by the manufacturers. These units will have insulation, dual heating elements, one sized for the idling requirements and the other sized to supply the difference between idling and the new reduced operating load, and controls which incorporate the idling feature. Automatic covers may be warranted since the closed cover significantly reduces energy and solvent loss. Solvent vapor loss is a form of energy loss since each pound of escaping vapor carries away approximately 100 Btu's of energy. References 45, 46, and 47 outline degreaser features and operating procedures which reduce vapor loss.



A steam, electric, or gas heater is used to boil the solvent. The vapor level is maintained by a water jacket or by a water jacket and condensing coils. Condensate is collected in a trough, passed through a water separator, then returned to the degreaser. Some new machines have a freeboard chiller, refrigeration coils which produce a cold air blanket to help contain the solvent vapors. Ventilated units have ventilation ducts on the lateral sides. Some units employ activated carbon beds to remove solvent from the ventilator exhaust.

Figure 5. Typical Open-Top Vapor Degreaser Cross Section.

U. Congeneration

The concept of cogeneration, the on-site generation of electrical and process heat energy, is receiving increasing attention today. Cogeneration offers the possibility of cost and energy savings by allowing the use of low pressure exhaust steam from electrical power generation for process heat, thereby increasing overall fuel utilization. The plating industry is an obvious possibility for consideration since the plating process requires both direct current electrical energy and low temperature thermal energy. Calculations have been made to determine the economic feasibility of using the cogeneration concept in three of the survey plants.

The cogeneration system would consist of a boiler and back-pressure steam turbine - DC generator set. Many plating plants have existing low pressure boilers. However, in most cases, a new boiler would be required to provide steam for the turbine at the necessary temperature and pressure. The exhaust steam from the turbine would be used for process heat. This would be compatible since almost all of the survey plants use steam for process heat and most of the steam is supplied at low pressure. A 225 psig system was chosen for the analysis. A higher pressure system might be more efficient but would incur higher capital cost and increased operating expense through the need for better trained personnel. The turbine exhaust would be approximately 15 psig saturated steam which would be used for process heat. The boiler could be fired with natural gas, oil, coal, or other fuels. The system would provide only DC electrical energy and process heat requirements, that is, cleaning, rinsing, and plating baths and drying ovens already operating on steam. Since these loads occur at the same time, energy storage or procedural changes would not be required (see Figures 6 and 7).

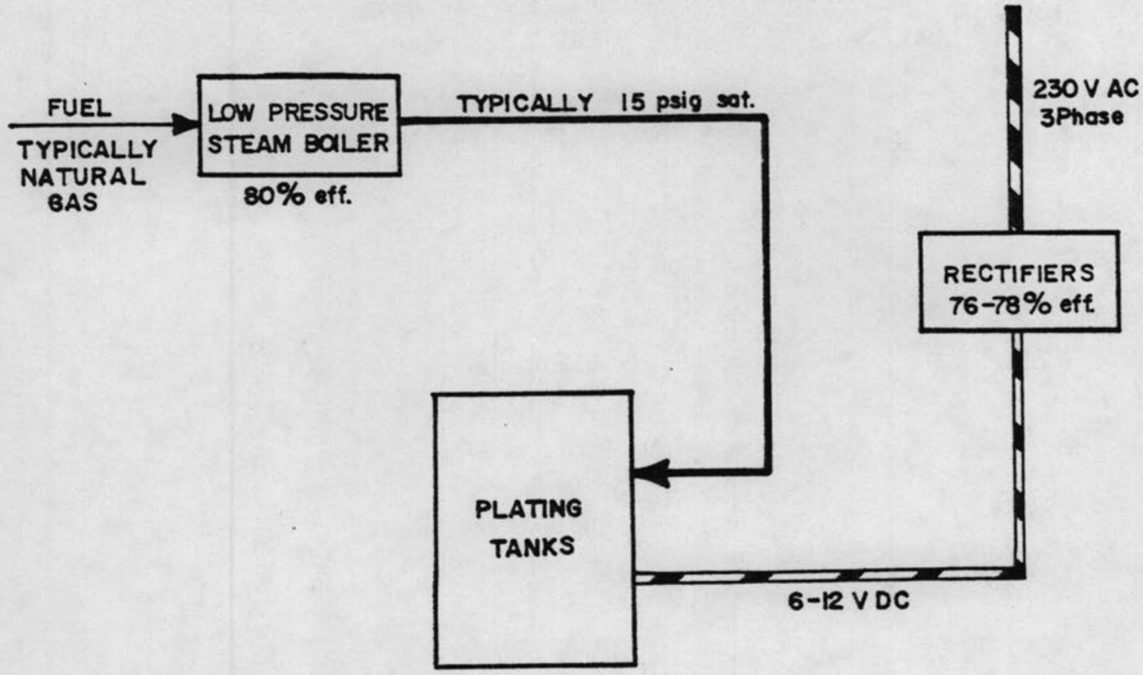


FIGURE 6 PRESENT PROCESS ENERGY USAGE

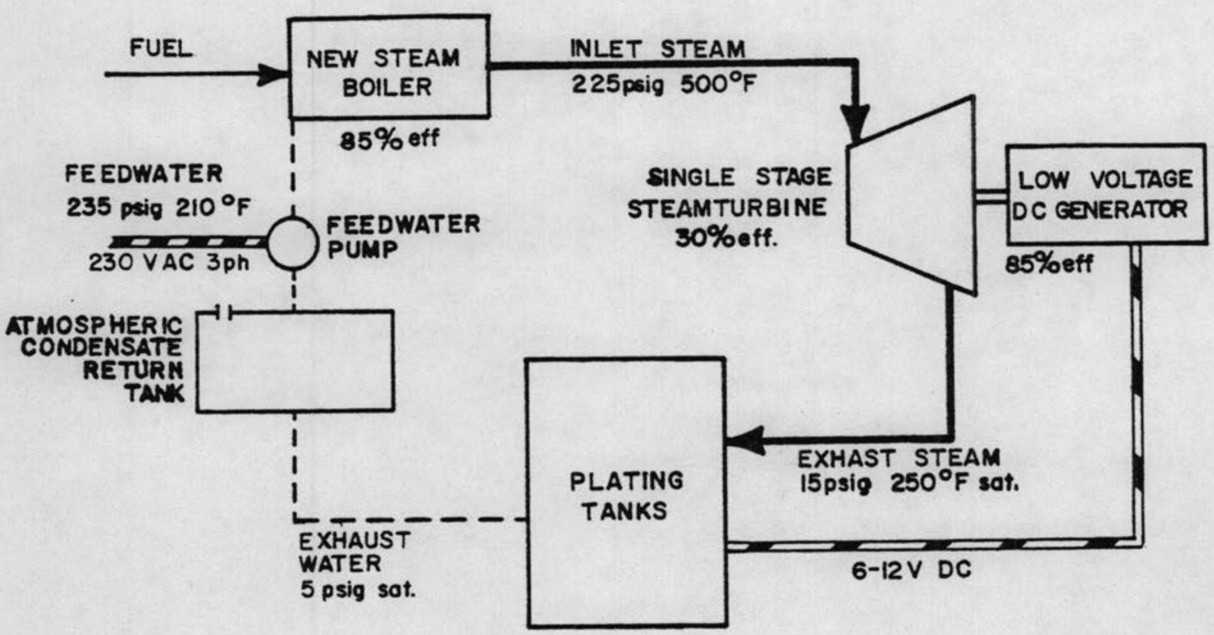


FIGURE 7 COGENERATION SYSTEM

One consideration, important to the design of a cogeneration system is the ratio of thermal energy usage to electrical energy usage; the heat to power ratio. The system must be designed so that the quantity of heat recoverable from the electrical power generation is less than or equal to the amount required for process heat. Also, the heat must be recoverable at a temperature high enough to meet the process requirements. The heat to power ratio of the cogeneration system varies with the choice of prime mover for the electrical power generation. A reciprocating internal combustion engine has a heat to power ratio of about 0.75:1. The heat to power ratio for large gas turbines ranges between 3:1 and 5:1.[48] The heat to power ratio for a steam turbine is much larger and can be varied to some extent by the choice of inlet and exhaust steam conditions. It is also dependent on the turbine efficiency. The turbine efficiency increases with turbine size, speed, and inlet pressure. The heat to power ratio decreases as turbine efficiency increases.

Plants I and N were chosen for the initial analysis. The calculations for Plant I are given in Appendix F. Plant I has a heat to power ratio of 3.1:1. The cogeneration system described above yields a three-fold increase in current yearly energy costs and a twelve-fold increase in energy usage. Plant N has a heat to power ratio of 14:1. With the cogeneration system, the current yearly energy cost increases by a factor of 1.6 and energy usage increases by a factor of 2.7. In each case, the exhaust steam from the turbine is in excess of process requirements. The same calculations were then carried out using the data on Plant F, which has a heat to power ratio of 49.5. This cogeneration system applied to Plant F results in an increase in energy usage by a factor of 1.4. The current yearly energy costs are about the same due to the low natural gas price. Here, the turbine exhaust does not meet total process requirements, necessitating bleed off of some steam upstream of the turbine. These costs and calculations are summarized in Table 10 for Plants I, N and F. Present and projected cogeneration system costs are shown.

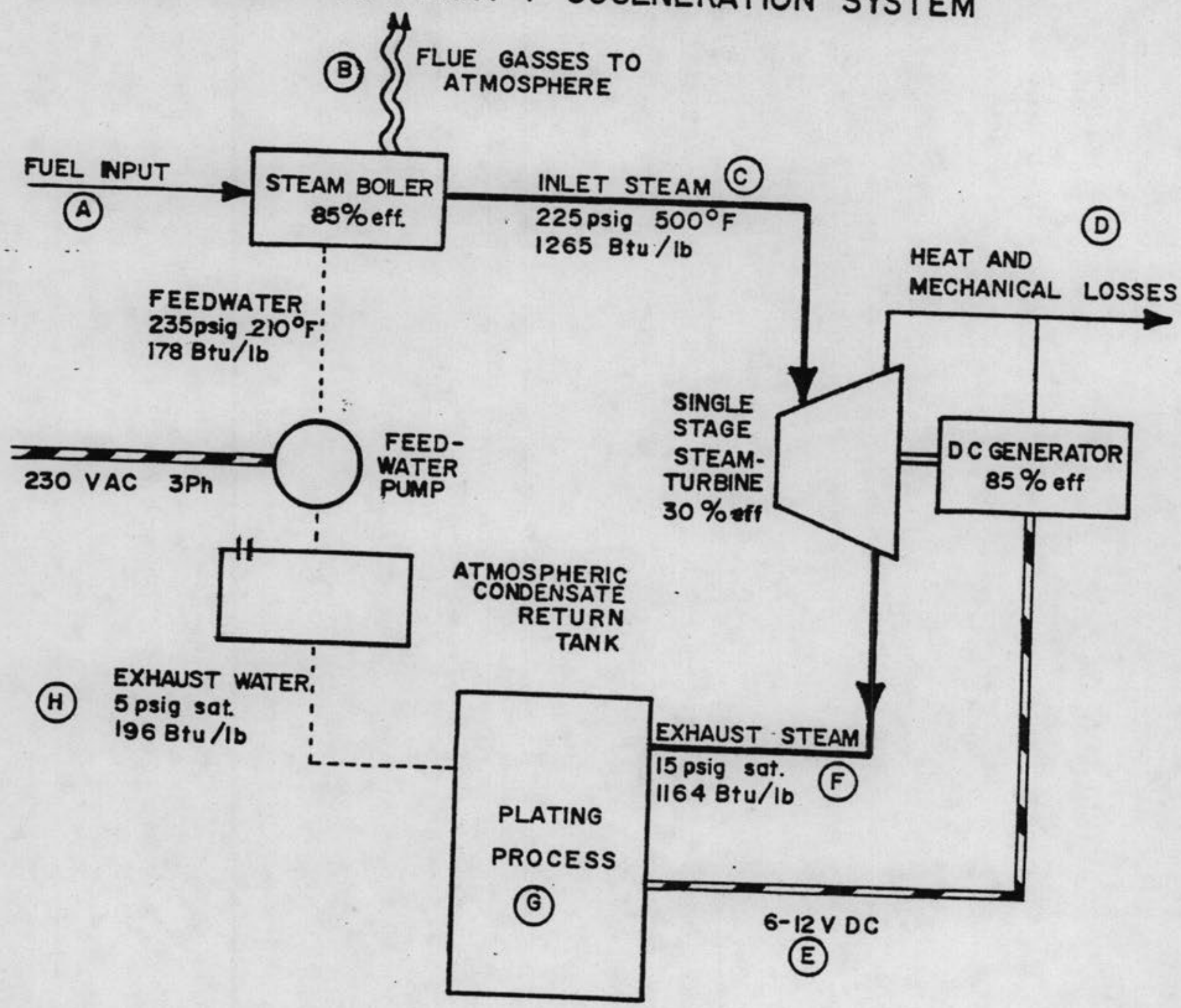
Given these assumptions, a cogeneration system is not presently economically feasible in the types of plants surveyed. The capital cost of the system would have to be balanced against annual savings in energy costs. It appears that there would be no savings. The capital cost for a cogeneration system of this type would be great. The turbine-generator set could cost as much as \$250,000.[49] In addition, a package boiler costing on the order of \$50,000 would be required. Installation costs would be incurred in addition to the equipment costs.

There are several factors contributing to the unfavorable results for cogeneration. The average DC electrical loads in the plants surveyed are small. They range between 10 and 450kw. As a consequence, small output, single stage turbines must be used. These units have efficiencies on the order of 30% at 225 psig. The boiler efficiency is about 85% and the DC generator has an efficiency of about 85%. The efficiency of electrical generation is around 24%, that is 24% of the energy given up by the steam as it expands through the turbine is converted to electrical energy. The pressure drop across the turbine is so small that less than 2% of the fuel energy is converted to electrical energy. So, while overall efficiency is about 70%, the electrical generating efficiency is quite low. The result is an increase in fuel usage with the congeneration system. An energy flow diagram for Plant F is given in Figure 8.

Cogeneration might be feasible, now or in the future, for certain plants. A plant with a large average electrical load, especially one with existing high

FIGURE 8

ENERGY FLOW FOR PLANT F COGENERATION SYSTEM



Branch	Description	Energy Flow Rate Btu/hr.
A	Heat equivalent of input fuel	1.98×10^6
B	Energy carried away by flue gases	2.97×10^5
C	Available energy in the inlet steam	1.68×10^6
D	Heat and Mechanical losses of generation	1.04×10^5
E	Electrical Output	3.57×10^4
F	Available energy in exhaust steam	1.54×10^6
G	Thermal Energy use for process	1.36×10^6
H	Energy contained in exhaust water	1.78×10^5

pressure steam generation, is a good candidate for cogeneration. Also, co-generation could become economically feasible for some plants in the event of rising electric rates combined with the availability of low cost fuel.

TABLE 10: Heat and Electrical Loads, Present Costs and Projected Costs for Cogeneration

	Plant	I	N Day Shift	N Night Shift	F
Present Cost	Annual Electricity $	30,750	19,618	9,800	2,400
	Annual N Gas $	10,900	44,500	22,250	23,000
Cogeneration System	Annual N Gas $	150,000	102,200	41,200	24,500
	Turbine Exhaust Energy $\frac{10^6 \text{ BTU}}{\text{hr}}$	7.85	16.2	6.5	1.32
	Boiler Fuel Energy $\frac{10^6 \text{ BTU}}{\text{hr}}$	12.4	25.6	8.16	1.98
	Steam lb/hr	8,300	17,100	6,800	1,400
Present System	Average Thermal Load $\frac{10^6 \text{ BTU}}{\text{hr}}$	0.766	5.94	2.37	1.75
	Average DC Load KW	73	125	50	10
	Process Thermal $\frac{10^9 \text{ BTU}}{\text{yr}}$	4.77	12.3	6.2	10.9
	DC Elec $\frac{10^5 \text{ KWHR}}{\text{yr}}$	4.58	2.54	1.27	0.645
	$\frac{\text{Thermal}}{\text{Electrical}}$ Ratio	3.06	14.2	14.2	49.5

V. POTENTIAL FOR ENERGY SAVINGS IN THE PLATING AND SURFACE FINISHING INDUSTRY

Potential Industry Energy Savings

Table 11 presents an estimate of the potential energy savings available for incorporating each of the listed energy conservation items for a single "worst-case" plant and for the industry as a whole, as represented by current practice in the twenty survey plants. It need be noted that the participating plants were not chosen on a statistical basis, and thus accuracy of the figures for the industry as a whole is questionable. Hopefully though, it is good enough to be useful in estimating conservation potential for the industry.

These estimates have been calculated from data taken in the survey plants as per current practice. For example, if modifying a drier from single pass operation to recycle operation will save 50% of its fuel usage, and the average oven and dryer heat energy usage in the twenty plants is 7.0% then, a plant representing the "worst-case" will have 7.0% of its heat energy consumed in dryers and could potentially save .5 (7.0%) = 3.5% of its heat energy usage. Since current practice in the twenty shops indicates that about 30% of the driers in service could potentially be modified to recycle operation, if we assume the twenty shops as being representative of the industry then the approximate industry wide savings would be about .3 (3.5%) = 1.0%.

TABLE 11

ENERGY CONSERVATION POTENTIALS

Item	Savings in a "Worst Case" Plant	Savings Industry Wide
Electrical		
Exhaust fans*		
Enclose plating lines to reduce ventilation requirements and thus reduce connected horsepower	18-20%	18-20%
Use of high efficiency ventilation hoods	12%	7.5%
More efficient fans to reduce horsepower requirements	4.0-5.0%	1.0-3.0%
Use of idler motors during off hours	3.0%	2.0%
Lighting		
Reduction of lighting energy consumption through all enumerated means	1.8%	1.4%
Agitation air		
Use of blowers for air requirements to replace air compressors	1.9%	.5%
Rectifiers		
Properly sized, maintained and operated at capacity	1.2%	1.2%
Space Cooling		
Isolate plating and thus reduce cooling requirements in the plant environment (applies only to those few plants with space cooling)	15-20%	.1-.2%

Process heat

Tank heating		
Insulation of tank walls	5.0%	5.0%
Use of ball blankets or tank covers where appropriate	3.0%	2.0%
Operating tank temperatures at recommended settings, not above	.3-.4%	.2-.3%
Eliminate the need for above ambient tank temperatures in the following areas:		
Process tanks	23.1%	23.1%
Rinse tanks	10.0%	10.0%
Cleaner tanks	12.0%	12.0%
Rinsing		
Use of cascade rinsing	5.0%	.5%
Input flow control to minimize heating requirements	1.0%	.2%
Boiler operations		
Tune-up regularly	1,0-2.0%	.2-.5%
Condensate return	5.2%	4.1%
Ovens/driers		
Recycle air systems installed on driers	3.5%	1.0%
Supplement to building heat	.5%	.5%
Space heating		
Use of infrared heaters as the sole source of comfort heating	50%	25%
Waste heat reuse from various sources	1.0-2.0%	1.0%

Note: Savings percentages are figured individually. For instance, if two or more of the items under exhaust fans were implemented the savings would not be the sum of the individual percentages but some lower value.

A large difference between the worst case percentage savings and the industry wide value indicates that most plants surveyed incorporate these items.

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APPENDIX A

PLANT ENERGY PROFILES

Plant A Energy Profile

Plant Characterization

Pounds of anode metals consumed annually

Nickel	2,300	
Copper	500	
Silver	750	(as salts and metal)
Gold	750	(as salts)

Plating includes: hand lines and manual barrel lines

Regional location: Northeast

Note: Plant A is unique for two reasons:

1) The work plated is small in size compared to other shops.
2) All tank heating is done electrically. Natural gas is used only for building heat in winter months, and for domestic purposes.

Electrical energy usage breakdown

Total annual kilowatthours 1.18×10^6

		Percent of total
1.	Plating	.9
2.	Lights	16.3
3.	Cracking furnace	3.4
4.	Tank heating	50.0
5.	Exhaust fans	10.4
6.	Filter and solution pumps	3.7
7.	Air compressors	5.8
8.	Vapor degreasers	3.5
9.	Barrel and tumbler drives	2.4
10.	Lab equipment	2.9
11.	Hoists	.7
		100.0%

Plant A (cont'd)

Process heat energy usage breakdown

Total natural gas usage 1977 approximately 59000 therms, 98.4 percent of which was consumed in plant heating. The remaining 1.6 percent was consumed in heating water for domestic use.

Plant B Energy Profile

Plant characterization

Pounds of anode metals consumed annually

Nickel	2,200
Chromium	6,000 (as salts, acid)
Copper	600
Zinc	3,750
Cadmium	200

Square feet of alumimum anodized annually: 105,000

Plating and anodizing include: hand lines, manual barrel lines and manual rack lines.

Regional location: Northeast

Electrical energy usage breakdown

Total annual kilowatthours 2.92×10^6

		Percent of total
1.	Anodizing	2.1
2.	Plating	7.1
3.	Electrocleaning	.2
4.	Lights	8.5
5.	Vapor degreasers (all electric)	11.1
6.	Heat treat ovens	13.8
7.	Chillers	4.7
8.	Exhaust fans	47.2
9.	Pumps: filters	3.2
10.	waste treatment	1.3
11.	Mechanical and air agitation	.7
12.	Hoists	.1
		100.0%

Plant B (cont'd)

Process heat energy usage breakdown

Total annual Btu's 9.01×10^{10}

	Percent of total
1. Process tanks	43.5
2. Rinse tanks	36.5
3. Boiler losses	20.0
	100.0%

Plant C Energy Profile

Plant characterization

Pounds of anode metals consumed annually

Zinc	45,000*
Chrome	300* (as salts)
Nickel	200*

* These are very approximate since accurate records were not available

Plating includes; automatic rack and barrel lines and hand lines.

Regional location: Southeast

Electrical energy usage breakdown

Total annual kilowatthours 8.58×10^5

	Percent of total
1. Plating	16.9
2. Electrocleaning	3.0
3. Lights	5.2
4. Exhaust fans and push/pull blowers	44.0
5. Hoists, barrel and spin dryer drives	12.2
6. Chiller	2.2
7. Filter pumps	2.1
8. All other pumps	2.3
9. Waste treatment	5.1
10. Sandblasting	.3
11. Dryer and boiler fans	2.5
12. Battery charger (fork trucks)	3.6
13. Air conditioning (summer)	.6
	100.0%

Plant C (cont'd)

Process heat energy usage breakdown

Total annual Btu's 9.31×10^9

		Percent of total
1.	Process tanks	6.1
2.	Rinses	14.6
3.	Cleaners	42.8
4.	Ovens and dryers	7.3
5.	Space heat	5.2
6.	Boiler losses	23.9
		100.0%

Plant D Energy Profile

Plant characterization

Pounds of anode metals consumed annually

Nickel	53,100
Chromium	45,200 (as salts)
Copper	40,500
Brass	48,600
Zinc	17,000

Plating includes: automatic rack and barrel lines, manual barrel lines and hand lines.

Regional location: Midwest

Electrical energy usage breakdown

Total annual kilowatthours 4.95×10^6

	Percent of total
1. Plating	54.1
2. Lights	8.5
3. Electrocleaning	1.8
4. Buffing	3.0
5. Exhaust fans	19.1
6. Filters	2.3
7. Blowers: dryers, air agitation, boiler	4.4
8. Pumps, recirculating	2.2
9. Waste treatment pumps	2.4
10. Drives and lifts	2.2
	100.0%

Process heat energy usage breakdown

Total annual Btu's 1.49×10^{11}

	Percent of total
1. Dryers	9.9
2. Process tanks	22.9
3. Rinses	41.4
4. Cleaners	9.3
5. Vapor degreasers	.3
6. Boiler losses	16.2
	100.0%

Plant E Energy Profile

Plant characterization

Pounds of anode metals consumed annually

Nickel	10,000	
Chromium	4,000	(as salts, acid)
Copper	500	
Cadmium	2,000	
Lead	2,000	

Plating includes: automatic rack, manual barrel and hand lines.

Regional location: Midwest

Electrical energy usage breakdown

Total annual kilowatthours 5.75×10^5

	Percent of total
1. Plating	25.7
2. Lights	14.3
3. Electrocleaning	11.3
4. Chiller	3.2
5. Exhaust fans	9.8
6. Filter pumps	6.1
7. Blowers; air agitation and boiler	13.5
8. Solution pumps	6.8
9. Waste treatment pumps and mixers	7.0
10. Hoists and drives	2.4
	100.0%

Process heat energy usage breakdown

Total annual Btu's 1.05×10^{10}

	Percent of total
1. Process tanks	14.3
2. Rinses	23.4
3. Cleaners	17.6
4. Space heating	11.4
5. Boiler losses	27.6
6. Oven	5.7
	100.0%

Plant F Energy Profile

Plant characterization

Pounds of anode metals consumed annually

Chromium 8,100 (as salts, acid)

Plating includes: automatic and manual rack lines.

Regional location: Southeast

Electrical energy usage breakdown

Total annual kilowatthours 3.03×10^5

	Percent of total
1. Plating	20.0
2. Lights	23.0
3. Electrocleaning	8.0
4. Exhaust fans	24.7
5. Boiler pumps	2.0
6. Demineralized water pumps	1.0
7. Spillage waste pumps	.2
8. Air compressor and agitation blowers	7.4
9. Hydraulic lift motor	12.4
10. Hoist motors	1.3
	100.0%

Process heat energy usage breakdown

Total annual Btu's 1.51×10^{10}

	Percent of total
1. Cleaners	33.7
2. Process tanks	9.6
3. Space heat	2.7
4. Evaporator for chrome recovery	28.9
5. Boiler stack loss	25.1
	100.0%

Plant G Energy Profile

Plant characterization

Pounds of anode metals consumed annually

None

Square feet of aluminum anodized annually

48.8 million

Plating includes: manual rack lines

Regional location: Southeast

Electrical energy usage breakdown

Total annual kilowatthours 4.45×10^6

	Percent of total
1. Anodizing	55.0
2. Lights	2.0
3. Chiller	20.0
4. Air compressor	2.5
5. Exhaust fans	8.0
6. Dryer blowers	4.0
7. Waste treatment pumps	7.0
8. Boiler feed, chemical feed pumps	1.0
9. Hoists and conveyors	.5
	100.0%

Process heat energy usage breakdown

Total annual Btu's 6.53×10^{10}

	Percent of total
1. Dryers	
a. gas	7.2
b. steam	19.1
2. Tank heating	42.0 (as below)
a. rinses	1.5
b. cleaners	1.5
c. brighteners	25.7

Plant G (cont'd)

	Percent of total
d. acetate	2.3
e. seal water	11.0
	42.0%
3. Boiler losses	23.2
4. Space heat	1.0
5. Sold as steam to adjoining firm	7.5
	100.0%

Plant H Energy Profile

Plant characterization

Pounds of anode metals consumed annually

Nickel	2,050	
Copper	7,600	
Cadmium	24,800	
Silver	2,050	(as salts and metal)
Gold	1,290	(as salts)

Plating includes: hand lines and manual barrel lines

Regional location: West Coast

Electrical energy usage breakdown

Total annual kilowatthours 9.92×10^5

	Percent of total
1. Plating	17.5
2. Lights	11.9
3. Electrocleaning	.2
4. Exhaust fans (with scrubbers)	46.8
5. Pumps; filters	9.0
6. recirculating	2.5
7. waste treatment	3.1
8. Mechanical and air agitation	2.0
9. Barrel and dryer drives	6.8
10. Hoists	.2
	100.0%

Process heat energy usage breakdown

Total annual Btu's 1.33×10^{10}

	Percent of total
1. Process tanks	14.5
2. Rinsing tanks	2.9
3. Cleaners	5.3
4. Vapor degreasers	48.6
5. Dryer	3.5
6. Boiler losses	25.2
	100.0%

Plant I Energy Profile

Plant characterization

Pounds of anode metals consumed annually

Cadmium	24,000
Zinc	100,000

Plating includes: automatic barrel lines and hand lines.

Regional location: West Coast

Electrical energy usage breakdown

Total annual kilowatthours 1.22×10^6

	Percent of total
1. Plating	46.0
2. Lights	8.3
3. Electrocleaning	3.4
4. Hoists	10.1
5. Barrel and spin dryer drives	8.2
6. Pumps waste treatment and others	2.2
7. Honing and tumbling	14.6
8. Air agitation	6.0
9. Exhaust, oven and dry off fans	1.2
	100.0%

Process heat energy usage breakdown

Total annual Btu's 1.03×10^{10}

	Percent of total
1. Process tanks	15.0
2. Rinses	20.4
3. Cleaners	10.9
4. Ovens and dryers	38.3
5. Boiler losses	15.4
	100.0%

Plant J Energy Profile

Plant characterization

Pounds of anode metals consumed annually

Nickel	26,000	
Chromium	3,000	(as salts and acid)
Copper	100	
Cadmium	500	
Silver	77	(as salts and metal)
Zinc	36,000	
Tin	500	

Plating includes: automatic barrel and rack lines and hand lines.

Regional location: Southeast

Electrical energy usage breakdown

Total annual kilowatthours 1.50×10^6

	Percent of total
1. Plating	33.0
2. Lights	26.0
3. Electrocleaning	4.0
4. Chiller	2.5
5. Exhaust fans	11.4
6. Filters and pumps	8.2
7. Air conditioners and heaters	3.0
8. Lathes and polishing wheels	1.3
9. Air agitation blowers and sand blaster	3.0
10. Hoists and drives	6.6
	100.0%

Plant J (cont'd)

Process heat energy usage breakdown

Total annual Btu's 2.46×10^{10}

	Percent of total
1. Process tanks	27.7
2. Cleaners	25.9
3. Rinses	15.5
4. Dryer	.9
5. Space heat	2.1
6. Boiler losses	23.0
7. Sold as steam to adjacent firm	4.9
	100.0%

Plant K Energy Profile

Plant characterization

Pounds of anode metals consumed annually

Nickel	5,000
Copper	25,000
Gold	260 (as salt)
Tin-lead	8,000

Plating includes: automatic rack lines and hand lines.

Regional location: West Cost

Electrical energy usage breakdown

Total annual kilowatthours 1.95×10^6

	Percent of total
1. Plating	2.8
2. Lights	9.9
3. Electrocleaning	.5
4. Exhaust fans	49.1
5. Air conditioning	25.2
6. Pumps; Filter	3.7
7. Waste treatment	4.9
8. Others	.4
9. Air and mechanical agitation	2.5
10. Barrel drives	.6
11. Dryer blowers	.4
	100.0%

Process heat energy usage breakdown

Total annual Btu's 1.44×10^{10}

	Percent of total
1. Tank heating (virtually all process)	36.3
2. Drying	1.3
3. Space heating	37.8
4. Boiler losses	24.7
	100.0%

Plant L Energy Profile

Plant characterization

Pounds of anode metals consumed annually

Nickel	75,000
Chromium	22,000
Copper	2,000
Zinc	28,000

Square feet of aluminmum anodized annually

25.0 million

Plating includes: automatic rack and barrel lines and hand lines

Regional location: Midwest

Electrical energy usage breakdown

Total annual kilowatthours 7.06×10^6

	Percent of total
1. Plating	24.9
2. Anodizing	15.1
3. Lights	21.0
4. Chillers	14.8
5. Electrocleaning	2.1
6. Exhaust fans	8.8
7. Pumps: hydraulic lift	2.0
8. filter	.7
9. recirculating and reclaim	1.0
10. acid	3.1
11. Barrel and auto plater drives	3.2
12. Dryer fans	1.3
13. Agitation air	2.0
	100.0%

Plant L (cont'd)

Process heat energy usage breakdown

Total annual Btu's 4.69×10^{11}

		Percent of total
1.	Plating and anodizing process tanks including brighteness tanks	10.4
2.	Anodizing seal water tanks	52.8
3.	Rinses	2.0
4.	Cleaners	5.2
5.	Space heat	4.3
6.	Dryers	5.2
7.	Boiler losses	20.1
		100.0%

Plant M Energy Profile

Plant characterization

Pounds of anode metals consumed annually

Nickel	1,000	
Chromium	100	(as salts and acid)
Copper	100	
Cadmium	2,200	
Silver	240	(as salts and metal)
Zinc	11,000	
Tin	515	

Plating includes: automatic rack and manual barrel lines and hand lines

Regional location: Midwest

Note: The substantial painting facilities at Plant L are included.

Electrical energy usage breakdown

Total annual kilowatthours 1.50×10^6

Plating area	Percent of total
1. Plating	6.8
2. Lights	14.3
3. Electrocleaning	.6
4. Electropolishing (stainless)	1.4
5. Exhaust fans	26.9
6. Pumps: waste treatment	2.3
7. filter and recirculating	1.1
8. parts washer spray	2.8
9. Tumbling	.4
10. Chillers	1.7
11. Barrel, spin dryer drives and hoists	1.4
12. Electric heat treat oven	1.1
13. Dry off and oven fans	1.5

Plant M (cont'd)

Paint Area

		Percent of total
14.	Pumps: spray	7.2
15.	recirculating	13.4
16.	Oven fans (bake and dry off)	3.3
17.	Paint cooler compressors	11.8
18.	Drives and mixers	1.4
19.	Air make-up fans	.6
		100.0%

Process heat energy usage breakdown

Total annual Btu's 3.76×10^{10}

		Percent of total
Plating area		
1.	Cleaners	5.5
2.	Rinses	10.5
3.	Process	4.2
4.	Vapor degreasers	9.3
Painting area		
1.	Cleaners	.5
2.	Rinses	.6
3.	Phosphating	.2
4.	Dry off oven	9.8
5.	Bake and cure oven	25.5
6.	Space heating	25.3
7.	Boiler losses	8.6
		100.0%

Plant N Energy Profile

Plant Characterization

Pounds of anode metals consumed annually

Nickel	76,700
Chromium	15,100 (as acid)
Copper	33,400

Square feet of aluminum anodized annually
100,000

Plating includes: automatic rack lines and hand lines

Regional location: Mid-central

Electrical energy usage breakdown

Total annual kilowatthours 1.71×10^6

		Percent of total
1.	Plating	26.4
2.	Lights	14.7
3.	Electrocleaning	2.8
4.	Anodizing	.2
5.	Exhaust fans	31.3
6.	Pumps: hydraulic lift	5.9
7.	recirculating, waste treatment and filters	2.3
8.	cooling tower	2.8
9.	Air agitation	3.1
10.	Polishing and buffing	9.5
11.	Honing and tumbling	1.0
		100.0%

Plant N (cont'd)

Process heat energy usage breakdown

Total annual Btu's 3.15×10^{10}

		Percent of total
1.	Rinses	1.1
2.	Cleaners	23.7
3.	Plating process tanks	29.8
4.	Anodizing tanks	1.6
5.	Curing ovens	2.0
6.	Space heat	28.8
7.	Chrome recovery evaporator	2.6
8.	Boiler losses	10.4
		100.0%

Plant O Energy Profile

Plant characterization

Pounds of anode metals consumed annually

Nickel	70,000
Chromium	24,000 (as acid)

Plating includes: manual rack lines

Regional location: Northeast

Electrical energy usage breakdown

Total annual kilowatthours 9.06×10^5

	Percent of total
1. Plating	41.1
2. Lights	8.6
3. Electrocleaning	4.3
4. Exhaust fans	16.0
5. Polishing, buffing	5.0
6. Blowers; air agitation, dryer, boiler	6.1
7. Filters	10.3
8. Air compressors (drive hoists)	8.2
9. Wash pump	.4
	100.0%

Process heat energy usage breakdown

Total annual Btu's 1.42×10^{10}

	Percent of total
1. Process tanks	48.5
2. Boiler losses	16.2
3. Dryer oven	5.7
4. Space heat	29.7
	100.0%

Note: All cleaners and rinses are ambient.

Plant P Energy Profile

Plant characterization

Pounds of anode metals consumed annually

Nickel	13,700
Chromium	4,540 (as salts)
Copper	1,510
Cadmium	3,770
Brass	40
Zinc	72,300

Plating includes: automatic barrel and rack lines, manual barrel and rack lines and hand lines.

Regional location: Mid-central

Electrical energy usage breakdown

Total annual kilowatthours 2.63×10^6

	Percent of total
1. Plating	19.2
2. Electrocleaning	4.4
3. Lights	10.1
4. Exhaust fans	33.6
5. Blowers; dryer, boiler etc.	4.6
6. Ovens and dryer heat	17.4
7. Filters	2.2
8. Other pumps	2.4
9. Hoists and drives	6.0
	100.0%

Process heat energy usage breakdown

Total annual Btu's 1.89×10^{10}

	Percent of total
1. Process tanks	25.9
2. Rinses	2.8
3. Cleaners	20.4
4. Space heat	25.6
5. Boiler losses	25.3
	100.0%

Plant Q Energy Profile

Plant characterization

Pounds of anode metals consumed annually

Nickel	120,000	
Chromium	3,000	(as salts)
Copper	125,100	
Gold	185	(as salts)

Square feet of aluminum anodized annually

4.0 million

Plating includes: automatic rack and hand lines.

Regional location: West Coast

Electrical energy usage breakdown

Total annual kilowatthours 1.31×10^7

		Percent of total
1.	Plating	5.0
2.	Anodizing	1.3
3.	Lights	14.3
4.	Electrocleaning and vapor degreasing	.2
5.	Exhaust fans, scrubber fans, push/pull blowers	13.0
6.	Polishing and buffing	7.8
7.	Injection molding department	30.2
8.	Paint and stress relief ovens	1.4
9.	Filter pumps	3.1
10.	Waste treatment pumps and mixers	2.0
11.	All other pumps	5.7
12.	Chillers and air conditioners	2.8
13.	Dryer and oven blowers	2.6
14.	Mechanical and air agitation	4.6
15.	Compressed plant air	4.6
16.	Drives, lifts and hoists	1.4
		100.0%

Plant Q (cont'd)

Process heat energy usage breakdown

Total annual Btu's 8.07×10^{10}

		Percent of total
1.	Process tanks	26.8
2.	Rinses	3.1
3.	Cleaners	6.3
4.	Dryers	19.0
5.	Vapor degreaser stills	7.6
6.	Heat treat ovens	4.3
7.	Paint shop ovens	2.9
8.	After burners on paint shop ovens	13.9
9.	Space heat	.4
10.	Boiler losses	15.7
		100.0%

Plant R Energy Profile

Plant characterization

Pounds of anode metals consumed annually

Nickel	1,650	
Copper	112,383	
Gold	488	(as salts)
Solder	25,200	
Tin	13,440	

Plating includes: automatic rack lines and hand rack lines.

Regional location: Midwest

Electrical energy usage breakdown

Total annual kilowatthours 3.40×10^6

		Percent of total
1.	Plating	1.3
2.	Electrocleaning	.6
3.	Lights	8.4
4.	Ovens	12.0
5.	Air conditioning (summer)	17.1
6.	Exhaust fans and push/pull blowers	34.7
7.	Vapor degreaser heaters	1.9
8.	Waste treatment	6.8
9.	Filter pumps	.8
10.	All other pumps	.2
11.	Hoists, drives, hydraulics	1.9
12.	Air and mechanical agitation	6.4
13.	Dryer and boiler blowers	.1
14.	Tank heating; process	4.4
15.	cleaners	2.2
16.	rinses	1.2
		100.0%

Plant R (cont'd)

Process heat energy usage breakdown

Total annual Btu's 1.04×10^9

	Percent of total
1. Cleaners	1.9
2. Rinses	1.5
3. Process	3.1
4. Vapor degreaser stills	.9
5. Boiler losses	2.1
6. Space heat	90.6
	100.0%

Plant S Energy Profile

Plant characterization

Pounds of anode metals consumed annually

Chromium	22,400 (as salts)
Copper	26,057
Zinc	10,000

Plating includes: automatic rack and manual hoist lines.

Regional location: Southeast

Electrical energy usage breakdown

Total annual kilowatthours 1.45×10^6

	Percent of total
1. Plating	50.7
2. Electrocleaning	3.2
3. Lights	5.0
4. Exhaust fans	16.6
5. Agitation air	1.4
6. Grinding, polishing, sand blasting	4.9
7. Stripping	1.4
8. Waste treatment	2.2
9. Filters	.9
10. Other pumps	6.2
11. Dryer fans	3.3
12. Drives and hoists	3.9
13. Heat treat oven	.3
	100.0%

Plant S (cont'd)

Process heat energy usage breakdown

Total annual Btu's 1.26×10^{10}

		Percent of total
1.	Process tanks	14.6
2.	Cleaners	10.9
3.	Rinses	3.7
4.	Dryer	8.2
5.	Waste-saver stills	43.7
6.	Boiler losses	18.8
		100.0%

Plant T Energy Profile

Plant characterization

Pounds of anode metals consumed annually

Nickel	70
Chromium	20 (as salts)
Cadmium	50
Silver	15 (as salts and metal)

Plating includes: hand lines.

Regional location: Southeast

Electrical energy usage breakdown

Total annual kilowatthours 3.90×10^5

	Percent of total
1. Plating and electrocleaning	.2
2. Lights	4.4
3. Exhaust fans	38.7
4. Heat treat oven	40.0
5. Waste treatment	7.2
6. Filters	.8
7. Mechanical Agitation	.4
8. Other pumps	8.3
	100.0%

Process heat energy usage breakdown

Total annual Btu's 2.96×10^9

	Percent of total
1. Process tanks	23.3
2. Cleaners	18.9
3. Rinses	21.8
4. Vapor degreaser	14.0
5. Boiler losses	22.0
	100.0%

APPENDIX B

EXAMPLE CALCULATIONS

Electrical Usage - Plating

Apply Faraday's Law in the following form:

$$\text{grams deposited} = \frac{\text{Molecular Wt X Energy consumed (calories)}}{\text{Molar equivalent X 23,060 } \frac{\text{cal}}{\text{volt e.g.}} \text{ X voltage applied}}$$

For example zinc:

$$(36{,}000 \text{ lbs}) \ 454 \text{ grams/lb} = \frac{65.4 \text{ X (calories)}}{2 \text{ x } 23{,}060 \text{ X } 7.5}$$

Where 7.5 volts is the average applied, half at 3 volts rack plating and half at 12 volts barrel plating. This is the approximate work distribution.

The calories delivered are then

$8.6 \text{ X } 10^{10}$ cals

assuming a 72 percent overall efficiency for rack plating and 40 percent for barrel plating and converting to kwhs:

$$8.6 \text{ X } 10^{10} \text{ cals } \frac{2}{(.72 + .40)\text{eff}} \text{ X } 1.16 \text{ X } 10^{-6} \text{ kwhs/cal} =$$

$1.75 \text{ X } 10^{5}$ kwhs consumed.

Lighting

A plating shop has 10,750 watts of fluorescent lighting and 3500 watts of incandescent lighting operating 5 days a week 20 hours a day. The energy consumed is then

(10,750 watts)(1 kw/1000 watts)(20 hrs/da)(5 da/wk)(52 wk/yr) =

55900 kwhs/yr

add 20% to drive the lighting ballast

(55900) 1.2 = 67,100 kwh/yr.

(3500)(1 kw/1000 watts)(20 hr/da)(5 da/wk)(52 wk/yr) =

18,200 kwh/yr

The sum of the two usages gives the total plant lighting consumption as 85,300 kwhs/yr.

Electrocleaning

Energy consumption for two electrocleaning stations is calculated as follows:

#1	300 amps @ 6 volts	120 hrs/wk
#2	1000 amps @ 9 volts	60 hrs/wk

#1 (300 amp)(6v)(120 hrs/wk)(1 kw/1000 watts)(50 wk/yr) =

10,800 kwhs/yr

#2 (1000 amp)(9v)(60 hrs/wk)(1 kw/1000 watts)(50 wk/yr) =

27000 kwhs/yr

For a total of 37,800 kwhs/yr.

Motors

A 25 hp air compressor motor draws 50 amps on each leg of a 3 phase circuit at 220 volts. The unit runs 10 hours a day, 52 week a year, 5 days a week.

(220 volts) (50 amps)(1.732)(10 hrs/da)(5 da/wk)(52 wk/yr)(1 kw/1000 watts) =

(1 kw/1000 watts) = 49500 kwhs/yr

Process Heat Usage - Tank Heating

A plating tank is maintained at 180°F, 24 hours a day, 5 days a week. The tank dimensions are 6' long by 4' wide by 4' deep. No direct ventilation is provided. Heating is by steam at 15 psi through coils. Condensate is not returned.

Heat loss from the tank surface will be approximately:

(2100 Btu/hr ft^2)(24 ft^2)(24 hrs/da)(5 days/wk)(52 wks/yr) =

3.14×10^8 Btu/yr.

where the evaporative heat transfer coefficient of 2100 Btu/hr ft^2 has been taken from "Heat Losses from Tanks, Vats and Kettles", by Samuel J. Friedman April 1948.

The tank walls and bottom have an average heat transfer coefficient of 2.1 Btu/hr ft^2 °F, then

(2.1 Btu/hr ft^2 °F)(104 ft^2)(180° - 70°F)(24 hrs/da)(5 da/wk)(52 wk/yr =

1.50×10^8 Btu/yr

where the combined radiative and corrective heat transfer coefficient of 2.1 Btu/hr ft^2 °F has been taken from "Mark's Handbook" 7th edition copyright 1969.

The total Btu's needed then to heat this tank are:

$$(3.14 + 1.50) \times 10^8 \text{ or}$$

$$4.64 \times 10^8 \text{ Btu/yr.}$$

In addition to these direct energy losses, the steam condensate which is not returned to the boiler represents another energy loss associated with heating this tank. For one pound of steam at 15 psi the heat content of the steam is 1134 Btu/lb (from the international steam tables) and the sensible heat available above the ambient water temperature of 60° is 152 Btu/lb. Thus, the hot condensate contains

$$\frac{152}{1134}\ 100 = 13\% \text{ of the}$$

total available heat, which is not effectively used. The total then of 4.64×10^8 Btu is 100-13 = 87% of the actual consumption. Or to heat this tank consumes approximately.

$$\frac{4.64 \times 10^8}{.87} = 5.33 \times 10^8 \text{ Btu/yr.}$$

APPENDIX C

EXAMPLE BUS BAR CURRENT OPTIMIZATION CALCULATIONS

Example Bus Bar Current Optimization Calculations

Example 1

Single 1/4" x 4" copper bar for a 20°C ambient

Use $$I = \frac{24.9 \times a^{1/2} \times p^{0.39} \times \Theta^{0.61}}{\sqrt{(1 + \alpha\ \Theta)\rho}}$$

$a = 6.452\ cm^2$

$p = 21.59$ cm

$\alpha = 0.00393$ 1/°C @ 20°C ambient

$\rho = 1.7241$ microhm cm @ 20°C ambient

Θ (°C)	I amps
50	1587
40	1408
30	1202
20	956
10	638

Compute heating loss

$R = (1 + \alpha\ \Theta)\rho \div a$

$R(ohm/ft) = 1 + 0.00393\ \Theta)\ 0.67879 \times 10^{-6}$ ohm in $\div$ 1 $in^2 \times 12$ in/ft

$L = I^2R$

Θ (°C)	I (amps)	L (watts/ft)
50	1587	24.55
40	1408	18.69
30	1202	13.16
20	956	8.030
10	638	3.446

Use these points to generate a function L(I) using a least squares procedure. Let L(I) be of the following form.

$$L(I) = a_1 I + a_2 I^2$$

We want to minimize the sum of the square of the error, $[L - (a_1 I + a_2 I^2)]$.

$$s = \Sigma (L - a_1 I - a_2 I^2)^2$$

Set the partial derivatives equal to zero.

$$\frac{\partial s}{\partial a_I} = 0 = \Sigma\, 2(L - a_1 I - a_2 I^2)(-I)$$

or

$$0 = \Sigma(LI - a_1 I^2 - a_2 I^3)$$

$$\frac{\partial s}{\partial a_2} = 0 = \Sigma\, 2(L - a_1 I - a_2 I^2)(-I^2)$$

or $\quad 0 = \Sigma(LI^2 - a_1 I^3 - a_2 I^4)$

Now find the following:

$$\Sigma LI = 90970$$
$$\Sigma LI^2 = 1.266 \times 10^8$$
$$\Sigma I^2 = 7.2668 \times 10^6$$
$$\Sigma I^3 = 9.6583 \times 10^9$$
$$\Sigma I^4 = 1.3362 \times 10^{13}$$

Solve these simultaneous equations for a_1 and a_2

$$90970 = 7.2668 \times 10^8\ a_1 + 9.6583 \times 10^9\ a_2$$
$$1.266 \times 10^8 = 9.6583 \times 10^9\ a_1 + 1.3362 \times 10^{13}\ a_2$$

$$a_1 = -7.487 \times 10^{-7}$$

$$a_2 = 9.475 \times 10^{-7}$$

Now use the expression for optimum value of I from the general discussion.

Use the following values

$$
\begin{aligned}
p_m &= \$1.32/\# \\
W &= 3.88\ \#/\text{ft} \\
f &= 0.40212\ \$/\text{yr}/\$\ \text{(3 yr payback for 10\% cost of capital)} \\
H &= 6240\ \text{hr/yr (3 shift, 5 day week)} \\
p_e &= \$0.03/\text{kwhr} \\
\eta &= 0.80 \\
\ell &= \$2.00/\text{ft}
\end{aligned}
$$

$$
I = \left[\frac{(3.88)(1.32)\ 0.40212 + (2.00)(0.40212)}{(9.475 \times 10^{-6}(\frac{1}{1000})(6240)(0.03)(1/0.80)} \right]^{1/2} = 1136 \text{ amps}
$$

Example 2

3-1/4" x 4" copper bars $\quad M = .84 \quad I_3 = .84\, I_1, \quad L_3 = (.84)^2\, I_1$

ΔT (°C)	I (amps)	L (watts/ft)	L(I) (watts/ft)
50	1333	17.70	17.537
40	1183	13.48	13.59
30	1010	9.50	9.663
20	803	5.81	5.836
10	536	2.49	2.306

$$L = a_1 I + a_2 I^2$$
$$s = \Sigma\,(L - a_1 I - a_2 I^2)^2$$

$$0 = \frac{ds}{da_1} = \Sigma\, 2(L - a_1 I - a_2 I^2)(-I) = \Sigma(LI - a_1 I^2 - a_2 I^3)$$
$$0 = \frac{ds}{da_2} = \Sigma\, 2(L - a_1 I - a_2 I^2)(-I^2) = \Sigma(LI^2 - a_1 I^3 - a_2 I^4)$$

$\Sigma\, L\, I$	$\Sigma\, L\, I^2$	$\Sigma\, I^2$	$\Sigma\, I^3$	$\Sigma\, I^4$
55136	6.447×10^7	5.129×10^6	5.726×10^9	6.655×10^{12}

$$a_1 = -1.6526 \times 10^{-3}$$
$$a_2 = 1.1109 \times 10^{-5}$$

Let

$p_m = \$1.32/\#$
$W = 3.88\ \#/ft$
$\ell = \$2.00/ft$
$f = 0.40212\ \$/yr/\$$

$H = 6240$ hr/yr

$p_e = \$0.03$/kwhr

$\eta = 0.80$

$$I = \left[\frac{(3.88)(1.32)(0.40212) + (2.00)(0.40212)}{(1.1109 \times 10^{-5}) \frac{1}{1000} (6240)(0.03)(1/0.80)} \right]^{1/2} = 1050 \text{ amps}$$

TABLE 12

ANNUALIZING FACTORS f ($\frac{\$/year}{\$}$)

k % \ N yr/yr	1	2	3	4	5	10	15	20
5	1.05	0.5378	0.3672	0.2820	0.2310	0.1295	0.0963	0.0802
10	1.10	0.5762	0.4021	0.3155	0.2638	0.1627	0.1315	0.1175
15	1.15	0.6151	0.4380	0.3503	0.2983	0.1993	0.1710	0.1598
20	1.20	0.6545	0.4747	0.3863	0.3344	0.2385	0.2139	0.2054
25	1.25	0.6944	0.5123	0.4234	0.3718	0.2801	0.2591	0.2529
30	1.30	0.7348	0.5506	0.4616	0.4106	0.3235	0.3060	0.3016

APPENDIX D

COMPARISON OF THE ADDITIONAL COST OF ENERGY SAVING FLUORESCENT LAMP TO THE RESULTANT MONETARY SAVINGS

Comparison of the Additional Cost of Energy Saving Fluorescent Lamps to the Resulting Monetary Saving

Reduced wattage, energy saving fluorescent lamps can be used to reduce energy consumption and lighting operating costs. The energy saving version of an 8 foot, T12, instant start lamp produces 14% less light than the standard lamp but uses over 20% less energy. The potential power savings is approximately 17.5 watts per lamp. The additional first cost is 10¢ per lamp while the average lamp lives are equal. For a plant lighted by 200, 8 foot, 2-lamp fluorescent fixtures, the total additional first cost to the plant is $40.00. The following table shows the yearly dollar savings for the plant for 1, 2, and 3 shift operation at 2, 3, and 4¢/KWhr energy costs.[50]

TABLE 13: RESULTANT SAVINGS (DOLLARS)

		Number of Shifts of Operation		
		1	2	3
Cost of Electricity (¢/KWhr)	2	$291	$ 582	$ 873
	3	436	872	1308
	4	582	1165	1747

APPENDIX E

EXAMPLE CALCULATIONS FOR BLOWER-AIR COMPRESSOR COMPARISON

Typical Nickel-Chromium Plating Line

Assumptions

Plating Line 4 feet wide x 4 feet deep

12 - 2'x 4' air agitated rinse tanks - 96 ft^2 @ 1.5 cfm/ft^2 - 144 cfm

1 -15'x 4' air agitated nickel plating tank - 60 ft^2 @ 1.5 cfm/ft^2 - 90 cfm

234 cfm

Total air volume flow rate requirement

Air supplied at 1 psi/18 inches of solution depth

1 psi/18 inches x 48 inches = 2.7psi

Air Compressor

Reciprocating, 2-stage air compressor sized to deliver 800 cfm at 80psi

150 BHP required

150 HP rated motor 460v 3-phase 91% efficient at full load

150 BHP x 0.7457 Kw/HP ÷ 0.91 = 123 Kw

The energy required to compress one cubic foot of air is computed as follows:

$$123 \text{ kwhr/hr} \div (800 \text{ ft}^3\text{/min} \times 60 \text{ min/hr}) = 2.56 \times 10^{-3} \text{ kwhr/ft}^3$$

Determine the volume ratio associated with the pressure ratio 94.7:17.4.

$$\frac{P_2}{P_1} = \frac{V_1}{V_2} = \frac{17.4}{94.7} = 0.1837$$

Where state 1 is at 80psig/ 94.7psia and state 2 is at 2.7 psig/17.4psia, at the same temperature.

The energy required to supply one cubic foot of air at 2.7 psig is given by the following:

$$0.1837 \text{ ft}^3 \text{ @ 80psig/ft}^3 \text{ @ 2.7psig} \times 2.56 \times 10^{-3} \text{ kwhr/ft}^3 \text{ @ 80psig} = 4.70 \times 10^{-4} \text{ kwhr/ft}^3 \text{ @ 2.7psig}$$

Centrifugal Blower

5 stage centrifugal blower sized to deliver 235 icfm at 2.7psig

5.8 BHP required

7.5 HP rated motor 230v 3 phase 85% efficient at full load

$5.8 \text{ BHP} \times 0.7457 \text{ kw/hp} \div 0.85 = 5.09\text{kw}$

The energy required to supply one cubic foot of air at 2.7psig is given by the following:

$$5.09 \text{ kwhr/hr} \div (235 \text{ ft}^3/\text{min} \times 60 \text{ min/hr}) = 3.61 \times 10^{-4} \text{ kwhr/ft}^3 \text{ @ 2.7psig}$$

Comparison

Energy Savings

$$4.70 \times 10^{-4} \text{ kwhr/ft}^3 - 3.61 \times 10^{-4} \text{ kwhr/ft}^3 = 1.09 \times 10^{-4} \text{ kwhr/ft}^3$$

Yearly Savings

$$\text{Operating time (hrs/yr)} \times 235 \text{ ft}^3/\text{min} \times 60 \text{ min/hr} \times 1.09 \times 10^{-4} \text{ kwhr/ft}^3 = \text{savings (kwhr/yr)}$$

TABLE 14: MONETARY SAVINGS RESULTING FROM SUBSTITUTING BLOWER AIR FOR COMPRESSOR AIR

Schedule	yearly energy savings (kwhr)	yearly operating expense savings ($) @ 3¢/kwhr	@ 4¢/kwhr	@ 5¢/kwhr
5 day/wk - 8 hr/day (2080 hr/yr)	3197	96	128	160
5 day/wk - 16hr/day (4160 hr/yr)	6394	192	256	320
5 day/wk - 24hr/day (6240 hr/yr)	9590	288	384	480

Investment Evaluation

Capital Cost   Spencer Turbine   Catalog Number 3007-H

$ 1958	blower and motor
85	freight
280	blast gate
$ 2323	
600	installation cost
2923	

Annual cost of the investment is given by

$$\left[\frac{\text{Capital Investment}}{\sum_{n=1}^{N} \frac{1}{(1+k)^n}}\right] = \text{Annual Investment Cost}$$

where N is the desired payback period and k is the cost of capital

TABLE 15

ANNUAL INVESTMENT COST IN DOLLARS

N(yrs) \ k(%)	5	10	15
3	921	1175	1280
5	580	771	872

The new equivalent annual worth is given as follows

New Equivalent Annual Worth = Annual Savings - Annual Investment Cost-Annual Maintenance Cost

Estimate the annual maintenance cost as 4% of the original equipment cost and take as an example, the 24hr/day plant at 5¢/kwhr and a desired payback time of three years at 10%

Net Equivalent Annual Worth = $480 - $1175 - $100 = -$795

The above calculations are before tax. Due to variable tax rates an example is excluded. Taxes can be accounted for in the following manner.

$$\text{Cost}_i = (1-T)(\text{Maintanenence Cost} + \text{Property Taxes})_i - T(\text{Depreciation}_i) - (\text{Investment Tax Credit})_i$$

$$\text{Savings}_i = (1-T)(\text{Annual Electricity Savings})_i$$

i = subscript indicating year in which cost is evaluated

T = combined corporate income tax rate, T= [federal tax rate + state tax rate X (1-federal tax state)]

$$\text{Net Equivalent Annual Worth}_i = \text{Savings}_i - \text{Cost}_i$$

APPENDIX F

COGENERATION CALCULATIONS FOR PLANT I

Cogeneration Calculations for Plant I

Total Energy Usage

1.22×10^{6} KWhr/yr electrical 1.03×10^{10} BTU/yr thermal

Process Energy Usage

Plating and electrocleaning accounts for 49.4% of the total electrical load or 6.03×10^{5} KWhr/yr. The rectifiers used to convert the alternating current to direct current are approximately 76% efficient. Therefore, the DC usage is approximately $0.76 \times 6.03 \times 10^{5}$ KWhr/yr $= 4.58 \times 10^{5}$ KWhr/yr.

Heating of tanks accounts for 46.3% of the total thermal load or 4.77×10^{9} BTU/yr.

4.77×10^{9} BTU/yr $\times 2.928 \times 10^{-4}$ KWhr/BTU $= 1.40 \times 10^{6}$ KWhr/yr

The thermal to electrical ratio is given by $\dfrac{1.40 \times 10^{6} \text{ KWhr/yr}}{4.58 \times 10^{5} \text{ KWhr/yr}} = 3.06$

Average Energy Loads

Plant I operates 24 hours per day, 5 days a wekk or a total of 6240 hours per year.

The average DC electrical load is given by 4.58×10^{5} KWhr/yr $\div$ 6240 hr/yr $= 73$ KW

The average process thermal load is 7.66×10^{5} BTU/hr.

Turbine Steam Requirement

The available energy in steam is given by the enthalpy in energy per unit of steam.

	Steam Conditions		Enthalpy
Inlet	225 psig	$500^{\circ}F$	1265 BTU/lb Steam
Exhaust	15 psig	$250^{\circ}F$	1165 BTU/lb Steam
Energy released in expanding through turbine			101 BTU/lb Steam

The theoretical steam consumption is given by

$$3412 \text{ BTU/KWhr} \div 101 \text{ BTU/lb steam} = 33.8 \text{ lb/hr - KW}$$

The DC load is 73 KW. Assume an 85% efficient DC generator. The turbine must produce 73 KW $\div$ 0.85 = 86 KW

86 KW X 33.8 lb/hr - KW = 2900 lb/hr theoretical. However, the actual turbine is approximately 35% efficient. The actual steam consumption is

$$2900 \text{ lb/hr} \div 0.35 = 8300 \text{ lb/hr}$$

Boiler Fuel Consumption

The boiler must supply 8300 lb steam/hr at 225 psig and 500° F. Assume the feedwater is preheated to 100° F.

	Condition	Enthalpy
Steam	225 psig 500° F	1265 BTU/lb Steam
Feedwater	235 psig 100° F	69 BTU/lb Steam
		1196 BTU/lb Steam

The energy required to produce the steam is

$$8300 \text{ lb/hr X } 1196 \text{ BTU/lb} = 9.93 \text{ X } 10^{6} \text{ BTU/hr}$$

The boiler is approximately 80% efficient.

$$9.93 \text{ X } 10^{6} \text{ BTU/hr} \div 0.80 = 1.24 \text{ X } 10^{7} \text{ BTU/hr}$$

The energy equivalent of natural gas is 1030 BTU/ft^{3}

$$1.24 \text{ X } 10^{7} \text{ BTU/hr} \div 1030 \text{ BTU/ft}^{3} = 1.20 \text{ X } 10^{4} \text{ ft}^{3}\text{/hr or}$$

12.0 MCF/hr

The yearly gas consumption is

$$12.0 \text{ MCF/hr X } 6240 \text{ hr/yr} = 74,900 \text{ MCF/yr}$$

Exhaust Steam for Process Heat

There is 8300 lb steam/hr at 15 psig and 250° F.

Assume the steam leaves the process heat exchangers as saturated liquid at 5 psig and 228° F.

	Condition		Enthalpy
Exhaust Steam	15 psig	250°F	1164 BTU/lb
Hot Water	5 psig	228°F	196 BTU/lb
Process Heat			968 BTU/lb

Available heat

8300 lb/hr X 968 BTU/lb = 8.03×10^6 BTU/hr

Process requirement 7.66×10^5 BTU/lb

The exhaust exceeds the requirement by a factor of 10.

Energy Costs

Present Cost of electrical energy

6.03×10^5 KWhr/yr X \$0.051/KWhr = \$30,750

Present cost of thermal energy for a boiler efficiency of 85%

4.77×10^9 BTU/yr ÷ 0.85 = 5.61×10^9 BTU/yr

5.61×10^9 BTU/yr ÷ 1030 BTU/ft^3 of gas = 5.45×10^6 ft^3 gas/yr

5.45×10^3 MCF/yr X \$2.00/MCF = \$10,900/yr

Cogeneration fuel cost

79,900 MCF X \$2.00/MCF = \$150,000/yr

APPENDIX G

ESTIMATE OF CURRENT INDUSTRY ENERGY USAGE

Estimate of Current Industry Energy Usage

Results of this study indicate that plating consumes approximately 24% of all electrical energy in the survey plants and that the ratio of fossil fuel energy consumption to electrical energy consumption is 5.97 to 1. If some approximation of total anode consumption can be made for the most heavily used metals, then some estimate of total industry energy consumption can be made. Recognizing that this approach assumes that the twenty plants surveyed are representative of the industry as a whole, and that they were not chosen on a strict statistical basis it must be concluded that this estimate is crude.

Industry sources indicate that anode consumption for 1977 was as follows:

Nickel	55	MMlbs
Chromium	80	MMlbs
Copper	35	MMlbs
Zinc	100	MMlbs
Tin	9	MMlbs

Application of Faraday's Law (as per Appendix B) indicates a total plating energy usage of approximately $3.0 \times 10^9 \frac{\text{Kwh}}{\text{yr}}$. Total electrical consumption is then:

$$\frac{3.0 \times 10^9}{.24} = 1.3 \times 10^{10} \frac{\text{Kwh}}{\text{yr}}$$

Total process heat energy usage then is:

$$(1.3 \times 10^{10} \frac{\text{Kwh}}{\text{yr}})\ 5.97\ (3414 \frac{\text{Btu}}{\text{Kwh}}) = 2.6 \times 10^{14} \frac{\text{Btu}}{\text{yr}}$$

The barrels of oil equivalent can be found by first converting the electrical energy to Btu's.

$$1.3 \times 10^{10} \text{ Kwh } (3414) \frac{\text{Btu}}{\text{kwh}} = 4.4 \times 10^{13} \text{Btu}$$

$$\begin{array}{r} 4.4 \times 10^{13}\text{Btu} \\ + \underline{2.6 \times 10^{14}} \\ 3.0 \times 10^{14}\text{Btu} \end{array}$$

$$3.0 \times 10^{14} \frac{\text{Btu}}{\text{yr}} \left(\frac{1 \text{ barrel}}{42 \text{ gallon}}\right) \quad \left(\frac{1 \text{ gallon}}{140{,}000 \text{ Btu}}\right) \quad =$$

$$5.2 \times 10^{7} \quad \text{or}$$

52 million barrels of oil equivalent.